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INTRODUCTION.

In a previons Annnal Report, it was stated that as tbe rising water-table approacbed a soil crust, tbe rate of rise decreased and no instance of a water-table entering tbe soil crust had been recorded. This statement is of great importance in connection witb tbe forecast of areas likely to become water-logged and of lesser importance regarding the development of Thur. During tbe past year a considerable numher of horings have been made and tbe conclusion bas generally been upbeld. The well level records which have been examined during the year also support the conclnsion. In tbe report of tbe Cbemical Section the records of a boring of particular interest are mentioned. This boring is exceptional in tbat on piercing tbe soil crust and tapping tbe underlying water, sand and water rushed into tbe bore, the final water level indicating tbat tbe water was under a pressure equivalent to 7ft bead of water. It has been beld tbat tbe final level of tbe water in tbe bore represents tbe deptb of tbe true water-table. This point of view is not at present accepted by the Irrigation Researcb Institute and furtber experimental work is in progress as a result of which it is boped to reach a definite conclusion.

Tbe distribution of salt in tbe soil crust bas been further studied. Tbe greatest variations in salt content in an unirrigated area occur in tbe top five feet of tbe soil crust. The diagram attacbed to the Cbemical Section report shows that soil profiles of higb and low salt content can occur side by side and, therefore, the lateral movement of salt is small while the vertical movement may be large.

In the Punjab, earth roads are the main means of communication between villages. Tbe factors determining the condition of these earth-roads bave heen under investigation for some time. This year particular attention has been devoted to tbe effect of salts on tbe state of the roads. The disintegrating effect of sodium sulphate and the heneficial effect of sodium chloride have been explained. Calcium chloride has been used in other countries for improving earth roads, tho improvement being due to the binding effect of the water absorbed hy this hygroscopic salt. It has heen shown that the same effect can he produced more cheaply hy using sodium chlorido. A method of treating roads affected hy sodium sulphate has heen suggested and is under investigation.

A suhject of considerable practical importance is the production of a mud plaster which is non-erodahle under rainfall or flowing water. This plaster has already heen successfnlly used on katcha huildings in some areas and its use is considerahly reducing maintenance charges. On two large farms minors and water-conrses have heen lined with the plaster. This has resnlted in a considerable saving

of water as indicated both by gauge readings and the area irrigated. In one area the smaller zemindars have adopted the process and the practice would spread quickly if Government would give an assurance that the water so saved would be available for use in the area served by the lined channels. The question is of considerable importance as it affords a solution of the problems connected with the increased intensity of irrigation which is a consequence of the fragmentation of holdings. The lining of water-courses will also be of value in connection with fodder production, a subject of considerable interest at the present moment.

An apparatus for measuring the capillary power of sands and soils in described. This is proving useful in connection with the introduction of sand layers under earth roads to prevent the rise of salts. By means of the apparatus, the mean diameter of sand particles can be approximately determined.

The design of tube-wells has been under further examination in the Physics Section. It has been shown that when the drawdown is small compared to the depth of water in the well, the yield of the tubewell is proportional to the drawdown. For other conditions which are of purely theoretical interest the linear relationship does not hold. An examination was made of the relationship between the diameter of the strainer and the yield of the tube-well. The sizes of the strainers used were the same as those usually employed in the field. The experiments did not support the general belief that the discharge of a tube-well is proportional to the diameter, and, therefore, to the surface area of the strainer. In a study of shrouding it has been shown that there is an optimum size of the shrouding material with reference to the grade of the water-bearing sand. For the average Punjab water-bearing sand, the most suitable particle size for the shrouding material is 3·5 mm. A large number of sands from borings were examined for their transmission constants to determine the most suitable positions for strainers.

Further work on the detection of cavities under weirs has been undertaken during the year. The apparatus used depends upon the vibrations set up by impacts on sound and unsound work. When the work is unsound, the amplitude of the vibration is greater than for sound work. Photographs illustrating the vibrations are attached to the report of this Section.

An investigation which is of considerable importance in connection with the interpretation of well records concerns the negative pressures developed in water films surrounding soil particles. It has been shown that wells are probably acting as manometers. In the field the greatest negative pressures are developed during the hot weather. The rainfall during the monsoon period flattens the concave menisci of the water films thus reducing the pressure deficiency. As a

result the water in the well shows a considerable rise which is out of all proportion to the rainfall received. The rise in well levels during the monsoon period does not, therefore, represent additions of water to the water-table.

In the Mathematical Section considerable time was spent on the model of the River Chenab at Khanki. The model when completed was handed over to the Hydraulic Section for the investigation of the river and silt control.

With the development of the drainage system of the Province fears had been expressed that certain drains might be increasing the seepage from canals. An investigation of the effect of a drain constructed at a distance of 1,200 feet from the Upper Gugera Branch, Lower Chenab Canal, on the seepage from the Branch was undertaken. The method of investigation is given in the report of the Section and the results show that this particular drain in its present position is not materially increasing the seepage from the canal.

The factors influencing the silt entry into the Lower Jhelum Canal are being studied. The tentative conclusion reached is that an increase in discharge in the river, an increase in the river slope and an increase in depth of silt in the pocket, all lead to increased silt entry into the canal. A further examination of the problem is in progress.

A start has been made on the study of silt movement in a tilting flume. Experiments have been started to find the frictional drag exerted by a sand bed of different grades on the flow of water in a channel. From the experiments so far conducted it has been possible to show that the law governing the velocity distribution in a smooth channel is identical with that obtained by Prandtl for smooth pipes.

During the year a series of hydraulic observations on the Mississippi River were published by the U.S. Waterways Experimental Station, Vicksburg. These have been examined to determine whether the slope-discharge-silt formula of the Irrigation Research Institute applied. It has been shown that the calculation of slope from the formula $S \times 10^3 = 2{\cdot}09 \dfrac{m^{\cdot 86}}{Q^{\cdot 21}}$ agrees well with the observed values. It seems probable, therefore, that the formula may be of more general application than was originally claimed.

The results obtained from the tube-well investigation in the Physics Section were examined in the Statistical Section. It has been shown that the discharge of a tube-well increases more rapidly than the drawdown and less rapidly than the length of the strainer. At very small drawdowns the discharge is directly proportional to the drawdown.

The relation between the rainfall and the rise in water-table has been examined for the lower half of the Rechna Doab. In this area the water-table is fairly deep and the rainfall low. A high correlation was obtained which does not support a suggestion that a high correlation would only be obtained when the water-table was near the surface. It was also pointed out that the water-table in this area has been showing a steady rise of 9 inches per annum over the last eighteen years and that there are no signs of a reduction in the rate of rise.

During the year hydraulic data were obtained for channels in the Gujranwala Division. It was found that the P=Q and R=Q relationships derived from observations on regime sites on other canals systems held well for the channels in the Gujranwala Division.

Considerable attention has been paid to seepage losses from canals. The mean monthly losses and their probable errors were worked out for various channels of the Lower Chenab Canal system for the last twenty years. It was found that the probable error was high as compared with the mean. The analysis of variance of the data is being undertaken.

Small experiments have been in progress to determine the effect of plant cover on run-off and soil erosion. At the observation site it was found that bare soil was eroded ten times as quickly as soil with a grass and scrub cover. The greatest loss of soil occurred during the monsoon months.

Two important investigations on river models have been in progress during the year in the Hydraulic Section. The tray in the laboratory was occupied by a model of the river downstream of Panjnad Weir for the study of methods that might be adopted to control bank erosion. A large bela has been formed downstream of the weir with the result that two channels have developed, the left channel taking one-third of the supply and the right channel two-thirds. Considerable erosion of the left bank has taken place and as a consequence the civil station has been endangered. The erosion of the right bank has been even greater than that of the left but from the point of view of Government property it is not so important.

The model showed that the best form of protection was the construction of two T. head spurs, the first situated 3,500 feet downstream of the weir line and the second 6,500 feet from the weir line. The investigation has shown that the spurs are most effective when the ratio

$$\frac{\text{Distance between the spurs}}{\text{Length of the spur}}$$

is between 4 and 5.

The second river model was constructed at Malikpur and the problems concerned the development of methods for the control of the River Chenab at Khanki weir. Owing to alterations in the method of regulation the right channel upstream of the weir has developed considerably and as a consequence the left channel has tended to silt up. The head regulator of the Lower Chenah Canal being situated on the left channel, some difficulty might be experienced in feeding the canal during periods of low supplies if the present conditions continued. Further, the bays of the weir on the right side might be subjected to very severe conditions during floods. The problems set out by the Chief Engineer are detailed in the report of this Section. An account is given of the measures that have been investigated. Two solutions seem to be possible (*a*) to allow the right channel to develop and feed the canal by flow across the weir, and (*b*) to construct a spur at Palku so that the channel to Bay 4 is developed which will allow control to be obtained of the supplies in the left branch. The effects of these alternative measures are still under examination.

A large scale model of the river immediately upstream of Khanki Headworks has also been under examination to determine the conditions most favourable to minimise silt entry into the canal and to secure the maximum efficiency of the silt excluder.

A model of Dhananra Regulator on the Western Jumna Canal has been under examination in one of the flumes. A silt excluder is now operating at the head of the Main Line Lower, Western Jumna Canal, and as a result considerable silt movement is to be expected on the bed. In order to stabilize the channel it was decided to flatten the slope by raising Dhanaura Regulator. The designs for the remodelling and the shape of the cistern to control the action downstream were examined. The design was especially considered with respect to the maximum co-efficient of discharge.

A model of the Jaha Level Crossing and the torrent in which it is situated was also constructed. From time to time the crossing has had to be extended in order to counteract the effects of retrogression. An attempt has been made to re-design the crossing to give maximum stability and the control of the retrogression is now being studied.

Silt surveys of the Upper Bari Doah Canal, the Lower Chenah Canal and the Western Jumna Canal have been in progress during the year. The silt work on the Upper Bari Doab Canal has been carried out with special reference to the proposed construction of a silt excluder at the head of the Main Line. With the river conditions and silt entry as at present there should be no difficulty in extracting the majority of the silt which is causing trouble on the branches.

The most important work of the Land Reclamation Section has been that connected with the appearance of Thur. Until recently it was thought that the formation of Thur was intimately connected with the rise of water-table and that when the water-table reached a certain distance (18 feet was stated) from the surface Thur began to make its appearance. A number of villages were selected so that a large range of depth of water-table could be studied with reference to the appearance of Thur in the future. Before selection no Thur had been reported in the selected villages. On surveying the villages it was found that Thur had appeared in each one although the range of depth of water-table was from 9 to 40 feet. It seemed, therefore, that the water-table was not an essential factor in the formation of Thur. A considerable number of profiles were examined and it was found that over a large area there is a zone of salt accumulation in the soil crust situated at different distances from the surface. The first conclusion reached was that the salt which gives rise to Thur is present originally in the soil crust and is not derived from the water-table. The experiments reported last year in connection with the formation of a zone of salt accumulation in tho soil crust under irrigation indicated that the factors responsible for the formation of Thur are probably associated with the water applied at the surface and the associated system of agriculture. As a result of further investigation, it seems probable that if tho water applied to the soil surface is insufficient to balance that lost by evaporation and transpiration than the balance of salt movement is in an upward direction and there is a tendency for Thur formation. As essential feature in the formation of Thur land is the sudden deterioration which takes place. It seems, therefore, that a concentrated salt solution is approaching the surface from below and that Thur is not due to the gradual concentration of salt in the surface layer by the evaporation of a dilute solution. An examination has been made of the intensity of irrigation during the Kharif season for the branches of the Lower Chenab Canal. On each branch the intensity of irrigation has increased considerably. The leaching of the salts from the surface layers which formerly took place with the heavier irrigations has ceased. A further factor which may assist in the recent increase in the Thur area in the poor monsoons of the past five years. It is recommended that in Thur danger areas a rice crop should be grown so that the salt may be removed from the soil crust to the underlying sand. Examples of the results of this process have been given and it has been shown that there is no tendency for a return to the deteriorated conditions over a period of eight years.

Several areas have been taken up for reclamation of Thur during the past year. On tho Renala Estate it has been shown that if reclamation is commenced as soon as Thur appears then the land can be reclaimed by one rice crop. It has also been demonstrated that

field drains for reclamation are not necessary in the Punjah if the water-table is more than five feot below the natnral eurface.

An investigation of open well irrigation was made in order that data regarding water requirements of crops and the cost of this form of irrigation might he available for the Officer on Special Duty, Tube Well Investigation. Valuable information regarding the discharge of open wells, the cost of irrigation and the factors determining the area irrigated hy a well have heen ohtained.

Three small catchment areas were placed under ohservation for run-off in connection with drainage requirements. It has been shown that in a cropped area very little of the rainfall runs off the surface of the land owing to the hunds around the cultivated fields. In nncropped arcas with heavy rainfall the run-off amounted to as much as 20·5 cusecs per square mile in onc case and in another to 22 cusecs pcr square mile.

During the run-off investigation, observations were made on the well levels in the areas. These observations afford interesting evidence of the magnitude of the negative pressurcs developed in eoil and the release of the negative pressnres by rainfall. The release of this negative pressure accounts for the apparent large rise in the water-table following a small rainfall at the end of a dry period.

A large part of the time of the General Section has been taken up hy the project work and reclamation echemes. The analyees of a large number of waters from exploratory horings in connection with tuhe-well projects have been made. An attempt has been made to classify the waters with reference to their liahility to cause choking of the strainers on account of calcinm carbonate deposition. A complete check has heen kept on the movements of salt in the eoil crust during the reclamation of areas on Renala Estate.

A survey of wheat soils with reference to yield and their chemical characteristics was undertaken in order to ohtain some information regarding the intial stages of soil deterioration. It is of interest that a significant correlation has heen ohtained hetween the yield of wheat and the available phosphate, as determined hy the CO^2 method. This would he expected in a country where the water snpply is one of the main factors limiting wheat prodnction. There is also a significant correlation hetween the manganese content of the soil and the yield of wheat. In general, soils giving a high yield of wheat have a low mangancse content and a low yield appears to be associated with a high manganese content. No information is availahle to decide whether manganese is exerting a direct effect or whethcr tho conditions euitable for the accnmulation of manganese are at the same time harmfol to wheat production.

CHEMICAL SECTION.

Rise of Water-Table with reference to the Soil Crust.—The rise of water-table and its consequences is a subject of great interest to this Province. Large areas have gone out of cultivation on account of the waterlogged conditions brought about by the rise of water-table almost to the ground level. Since salt, otherwise known as *kallar* or *thur*, is generally present in these soils, the position is aggravated by the development of high salinity in the waterlogged areas. It must be understood, however, that *thur* can appear on the soils surface irrespective of the depth of the water-table and areas have been known to go out of cultivation in which the water-table is too deep to have had any influence on the movement of salts.

It has been stated in previous reports that a general characteristic of the soil profiles of the Punjab alluvium is that they consist of a soil crust of varying thickness overlying a sand stratum. The nature and thickness of the soil crust profoundly influences the rising water-table which can freely move in sand, but is checked in its progress when it meets with the soil layer which may be partly or wholly impermeable to water. Since the nature of the soil is very important in determining its permeability to water, a definition of the soil crust that can prevent the rise of water-table seems called for. Obviously such an attempt is beset with difficulties because there is more than one factor involved. However, it can be stated, with a fair amount of justification, that for the purpose of this discussion a soil crust containing at least 15 per cent. clay and having a pH value not less than 8·5 and a salt content not more than ·5 per cent. will prevent the further rise of water-table when touching it. Such a soil crust when present to a depth of at least 10 feet will ensure that the area will not become waterlogged in consequence of a rising water-table. Soil profiles from more than a hundred different areas have been examined and in no case has an exception been found to this rule. It must be understood that the statement refers only to the cases of waterlogging produced by the rise of the subsoil water to the surface. Obviously it can have no application to low lying areas where flood water might collect and produce a state of waterlogging. It may be stated that 10 feet of soil crust should be quite effective in preventing any danger of waterlogging especially if the salt in the soil is not excessive. The limitation introduced by an excessive amount of salts is due to the enhanced permeability of the soil, which behaves as if it contained a smaller amount of clay in the presence of salts. High alkalinity and high clay content, on the other hand, by reducing permeability may decrease still further the minimum depth of soil crust required for checking the rising water-table.

The mechanism of moisture distrihution in a soil profile touching the water-tahle is largely the resnlt of a dynamic equilibrinm between two opposing forces, namely, the ahsorption and rise of water by capillarity and its loss hy evaporation at the surface. The maximum height to which water can rise hy capillarity is never more than 6 feet even in the heaviest clays and its rate of rise is limited hy the permeahility of the soil. If the soil crust is ahout 6 feet in thickness and the rate of evaporation less than the rate of capillary rise, the soil will have a more or less uniform moisture content throughout the profile down to the water-tahle. If on the other hand, the rate of evaporation is greater than the rate of capillary rise, the top portion will hecome dry and there will he a steep moisture gradient up to a certain depth from the snrface. This region of steep moisture gradient may extend to a few inches only when the soil crust is only 6 feet. When the soil crust is more than 6 feet, the portion above the limit to which the capillary may extend has a steep moisture gradient, and the portion within the capillary zone a uniform moisture content. Estimation of the moisture content of the soil profile, therefore, offers very valuahle information regarding the possibilities of water-logging in an area where the water-table is touching the soil crust. A very interesting case in connection with this investigation is given in detail hy way of illustration. The clay crust at R. D. 180,000 at a point 300 feet away from the Main Line, Lower Chenah Canal, is 13 feet in thickness. Soil samples were taken at every foot down to the water-tahle at this place on 29th Decemher, 1938. The following tahle shows the moistnre and clay contents of these samples :—

TABLE 1.

Showing the moisture and clay content at every foot down to the water-table at R. D. 180,000, Lower Chenab Canal.

Depth.	*Moisture %.*	*Clay %.*	
0—1′	4·8	16·3	
1—2′	6·1	13·8	
2—3′	10·1	27·7	
3—4′	13·9	19·4	
4—5′	20·2	22·1	
5—6′	23·3	24·6	Water rose to 6′—1″ on piercing the soil crust.
6—7′	23·1	24·5	
7—8′	23·3	18·2	
8—9′	22·9	19·2	
9—10′	24·5	26·6	
10—11′	26·5	17·2	
11—12′	26·4	21·3	
12—13′	25·7	24·4	
13—14′	34·5	7·1	Water-tahle situated at this depth.

It will be seen that the soil crust at this place is 13 feet. The sudden drop in clay content from 24·4 to 7·1 per cent. is typical of the line of demarcation between the soil crust and the sand stratum underneath. There is generally some mixing of the soil and sand at this junction but the difference in texture is striking and cannot be mistaken. The sudden increase in moisture content in the sand stratum is also characteristic of these profiles. For instance, in this particular case, the sample at the 13th foot contained 25·7% moisture which was just about equal to the field moisture capacity, but was below the rolling limit and the soil fell into pieces when worked in the hand. The sample from the 14th foot, on the other hand, was wet and water could be squeezed out of it by pressing it in the hand. This condition is so characteristic that there is no difficulty in locating the water-table without having to determine the moisture content. The exact moisture content, however, is determined in every case by immediately transferring a portion of the sample into a weighed lead tube which is at once sealed and subsequently examined in the laboratory for moisture content by drying at 100—110°C.

When the soil crust was pierced by the sampler, the water-table immediately rose in the bore hole with such a force that 3′—2″ of sand was also blown into it. The following table shows the rate of rise of water-table in the bore hole :—

TABLE 2.

Time after piercing the soil crust.	*Depth of water in the bore from natural surface.*
1 minute.	9′—8″
5 minutes	8′—1″
10 ,,	7′—0″
15 ,,	6′—9″
20 ,,	6′—7″
25 ,,	6′—6″
30 ,,	6′—5″
40 ,,	6′—4″
50 ,,	6′—3″
4 hours	6′—1″

It is a remarkable phenomenon that the water-table actually rose by about 7 feet when the soil crust was pierced. In other words, the subsoil water was exerting an upward pressure of this magnitude and yet could not pierce the soil crust. It might be argued that the water-table was actually at the 6th foot in the soil layer. This is hardly likely for the following reasons :—

(a) The moisture content of the soil below the 6th foot is lower than the saturation point. Samples from the 10th to the 13th foot were examined for their field moisture

The mechanism of moisture distribution in a soil profile touching the water-table is largely the result of a dynamic equilibrium between two opposing forces, namely, the absorption and rise of water by capillarity and its loss by evaporation at the surface. The maximum height to which water can rise by capillarity is never more than 6 feet even in the heaviest clays and its rate of rise is limited by the permeability of the soil. If the soil crust is about 6 feet in thickness and the rate of evaporation less than the rate of capillary rise, the soil will have a more or less uniform moisture content throughout the profile down to the water-table. If on the other hand, the rate of evaporation is greater than the rate of capillary rise, the top portion will become dry and there will be a steep moisture gradient up to a certain depth from the surface. This region of steep moisture gradient may extend to a few inches only when the soil crust is only 6 feet. When the soil crust is more than 6 feet, the portion above the limit to which the capillary may extend has a steep moisture gradient, and the portion within the capillary zone a uniform moisture content. Estimation of the moisture content of the soil profile, therefore, offers very valuable information regarding the possibilities of water-logging in an area where the water-table is touching the soil crust. A very interesting case in connection with this investigation is given in detail by way of illustration. The clay crust at R. D. 180,000 at a point 300 feet away from the Main Line, Lower Chenab Canal, is 13 feet in thickness. Soil samples were taken at every foot down to the water-table at this place on 29th December, 1938. The following table shows the moisture and clay contents of these samples :—

TABLE 1.

Showing the moisture and clay content at every foot down to the water-table at R. D. 180,000, Lower Chenab Canal.

Depth.	*Moisture %.*	*Clay %.*	
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1—2′	6·1	13·8	
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3—4′	13·9	19·4	
4—5′	20·2	22·1	
5—6′	23·3	24·6	Water rose to 6′—1″ on piercing the soil crust.
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7—8′	23·3	18·2	
8—9′	22·9	19·2	
9—10′	24·5	26·6	
10—11′	26·5	17·2	
11—12′	26·4	21·3	
12—13′	25·7	24·4	
13—14′	34·5	7·1	Water-table situated at this depth.

It will be seen that the soil crust at this place is 18 feet. The sudden drop in clay content from 24·4 to 7·1 per cent. is typical of the line of demarcation between the soil crust and the sand stratum underneath. There is generally some mixing of the soil and sand at this junction but the difference in texture is striking and cannot be mistaken. The sudden increase in moisture content in the sand stratum is also characteristic of these profiles. For instance, in this particular case, the sample at the 18th foot contained 25·7% moisture which was just about equal to the field moisture capacity, but was below the rolling limit and the soil fell into pieces when worked in the hand. The sample from the 14th foot, on the other hand, was wet and water could be squeezed out of it by pressing it in the hand. This condition is so characteristic that there is no difficulty in locating the water-table without having to determine the moisture content. The exact moisture content, however, is determined in every case by immediately transferring a portion of the sample into a weighed lead tube which is at once sealed and subsequently examined in the laboratory for moisture content by drying at 100—110°C.

When the soil crust was pierced by the sampler, the water-table immediately rose in the bore hole with such a force that 8′—2″ of sand was also blown into it. The following table shows the rate of rise of water-table in the bore hole :—

TABLE 2.

Time after piercing the soil crust.	*Depth of water in the bore from natural surface.*
1 minute.	9′—8″
5 minutes	8′—1″
10 ,,	7′—0″
15 ,,	6′—9″
20 ,,	6′—7″
25 ,,	6′—6″
30 ,,	6′—5″
40 ,,	6′—4″
50 ,,	6′—3″
4 hours	6′—1″

It is a remarkable phenomenon that the water-table actually rose by about 7 feet when the soil crust was pierced. In other words, the subsoil water was exerting an upward pressure of this magnitude and yet could not pierce the soil crust. It might be argued that the water-table was actually at the 6th foot in the soil layer. This is hardly likely for the following reasons :—

(a) The moisture content of the soil below the 6th foot is lower than the saturation point. Samples from the 10th to the 18th foot were examined for their field moisture

capacity without drying. It was found that except the sample from the 13th foot which was actually touching the water-table, they were all below their field capacity by 1 to 4 per cent. showing that there could not have been any free water.

(b) If the water-table had been actually at the 6th foot the soil above it would have shown a higher moisture content than what was actually found, because the capillary rise of water extends to 6 feet in these soils. This will be clear from the following table which gives the clay and moisture percentages in a soil profile taken on the same day at R. D. 175,000, Lower Chenab Canal, *i.e.*, only a mile away from the profile described before :—

TABLE 3.

Depth.	*Moisture %.*	*Clay %.*	
0—1′	12·9	19·2	
1—2′	18·3	22·6	
2—3′	20·8	16·6	
3—4′	23·0	17·7	
4—5′	25·9	13·4	
5—6′	30·3	14·2	Water-table.
6—7′	34·3	11·8	
7—8′	31·8	8·7	
8—9′	29·0	6·1	

The soil crust at this place is only 6-7 feet in thickness, the line of demarcation between the soil and the sand was not very sharp and there was no rise in the water-table when the soil crust was pierced. The moisture content of the soil right up to the surface is high. The rate of evaporation of moisture at R. D. 180,000 cannot be much higher than at R. D. 175,000. The steeper moisture gradient at R. D. 180,000 cannot be explained on any other assumption than that the water-table was actually not at the 6th foot. No case has been recorded in this investigation where the water-table was at a depth of six feet and the soil crust above it showed such a steep moisture gradient in this type of soil, nor can such a condition of steep moisture gradient be reproduced in the laboratory by placing a column of soil on a free water surface in a tube and subjecting it to evaporation from the top.

It has been shown that the moisture content of the soil even at the 12th foot was slightly below the field-moisture capacity. This condition is determined by kneading the soil with water until a drop of water placed on it is not absorbed and remains on the surface as free water. At this moisture content, the soil still has a considerable suction force and is by no means in a saturated state (*c.f.* Schofield

Trans. Third Int. Cong. Soil Sci. 2:37). This fact conld not he reconciled with tho supposition that the water-table was actually in this portion, unless a different meaning is assigned to the water-table than that generally understood. If it is conceded that a moisture content of 23-24 per cent. in a soil containing 22—24 per cent. clay corresponds to a condition in which the water-table is actually situated in it, then waterlogging would lose some of its worst features because at this moisture content in theso soils, it would be possible to raise crops without difficulty since this would bo the optimum moisture condition for plant growth.

The bore holo at R. D. 180,000 was kept under observation and in about two months the water-tablo stood at 5′—5″. Near this bore hole, a pit was dug on 26th January, 1939, and left at the 5th foot. In other words, the bottom of the pit was only 5″ above the water-table in this area. The pit was left for about a month during which time a lot of rain occurred and the pit had to be emptied several times. After a brief spell of fair weather samples were taken in the 1st foot of the bed of the pit on 25th March, 1939. The following table shows the moisture contents at different depths :—

Depth below the bottom of the pit.	*Moisture content.* %
0—1″	17·9
1—2″	20·3
2—3″	21·2
3—6″	24·1
6—9″	25·8
9—12″	27·7

It will be seen that the moisture content in the first inch is 17·9, this in spite of the fact that the apparent water-tablo in this area is within 5″ of the bottom of the pit. The soil crust at the bottom of tho pit is only 8 fect in thickness. Tho pit was next lowered by another 12″ on 26th March, 1939, giving a depth of the bottom at 6 feet below the natural surface. Rain occurred during this period and the pit had to be emptied twice. Within 48 hours of the removal of tho rain water tho pit again became dry at the bottom. On 6th April, 1939, there was rain and the pit was emptied on 7th April, 1939. On 8th April, 1939, at 2 P. M. it had developed a dry crust at tho bottom. The moisture contents of tho first four inches were as follows :—

Depth below the bottom of the pit.	*Moisture content.* %
0—1″	13:97
1—2″	18·42
2—3″	24·37
3—4″	27·15

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Exact measurements of the bed level with reference to the level of the water-table on this day showed that the bed of the pit was 7" lower than the apparent water-table and there should have been 7" of water standing in the pit, if the water-table had been able to pierce the soil crust. This shows that the water-table cannot pierce a clay crust of 7 feet even when it is subject to an upward thrust of more than 8 feet of water.

Another bore hole in this plot which was stopped at 7½ feet leaving a soil crust of 5½ feet was found to contain water in the hole after a week. This might imply that a rising water-table under an upward pressure of 7 feet could pierce a soil crust of 5½ feet and lead to waterlogging at the surface. The investigations are being continued in order to determine the conditions under which a water-table can enter the soil crust.

Movement of Moisture and Salts in Soils.—Soil samples down to 20 feet depth taken in an area 100′ × 100′ and divided into 100 squares of 10′ × 10′ show that the greatest variation in salts is confined to the first five feet depth. This will be clear from Fig. 1 in which the average salt content of 5 feet depths are given in the case of 100 squares. It is a remarkable fact that a salt content of 1·05 per cent. lies close to a square containing only 0·2 per cent. There is a very sharp line of demarcation between the areas of high and low salt content and the differences persist from year to year. Similarly a moisture content as low as 1·67 per cent. and as high as 12·99 per cent. can exist side by side. Fig. 2 shows in a striking manner the differences in moisture and salt percentage in two plots lying close together.

We find similar variations in clay content as well as in exchangeable calcium. A clay content of 5·0 per cent. can exist side by side with one of 28·0 per cent. and exchangeable calcium may differ from 3·0 milli-equivalents to 13·15 milli-equivalents within a short distance.

Salts play an important part in tropical countries in determining the conditions of earth roads. The appearance of the white [illegible] the [illegible] ions [illegible] soil during the cold winter nights, when the humidity may be as high as 100 per cent. and evaporated during the day when it may be as low as 30 per cent. The alternate absorption and evaporation of moisture being mainly responsible for the movement of salts in winter, it becomes necessary to study the effect of the nature and amounts of salts in soils on moisture absorption at various humidities. Different salts that are naturally found in soils or could be usefully incorporated with them, were added to a typical Punjab soil as well as to a heavy clay subsoil. Moisture absorption was studied on these soils in

atmospheres of constant relative humidities created by sulphuric acid water mixtures of varying concentrations. The results are plotted in Fig. 3. It will be seen that up to 70 per cent. humidity, the effect of salts on the hygroscopicity of the soil is practically negligible. Beyond this humidity, however, the hygroscopicity rapidly increases with increasing salt concentrations, so much so, that with 5 per cent. salt, the hygroscopicity at 98 per cent. relative humidity may be three times that of the soil without salt.

Moisture plays an important part in the preservation of road surfaces and prevention of the dust nuisance. The use of calcium chloride has been advocated for this purpose. It is believed that calcium chloride being hygroscopic will keep the soil moist. The results of these experiments show that within the economic limits of calcium chloride treatment, the soil is not rendered any more hygroscopic than it is with the use of other cheaper salts such as sodium chloride.

The stabilizing influence of salts that contain no water of hydration is two-fold. The soil is rendered more hygroscopic and remains moist for a longer period. The film moisture thus retained increases the cohesive forces keeping the particles bound together. In the extreme case when all the moisture has evaporated the minute salt crystals deposited in the interstices act as mortar in stabilizing the aggregate. The increase in the moisture retaining power of the soil due to salt is shown in Fig. 4, giving the rate of evaporation of moisture from soil surfaces stabilized with different salts.

Attention was next directed to the relation between the nature of the salt and the destruction of the road surface. Various salts commonly found in the earth roads were added to moist soil and the salt allowed to travel up to the surface by evaporation. It was discovered that the only salt that causes the characteristic loose and fluffy texture is sodium sulphate. Sodium chloride, on the other hand, may be present in any amount (up to 5 per cent. has been studied) but the road surface is maintained perfectly intact, and even better than that without salt. However, even a small amount of sodium sulphate, if present along with sodium chloride, causes the destruction of the surface. These results are of great practical importance, especially, as a possible remedy for the action of sodium sulphate might be found in the use of calcium chloride. It would appear that the adverse effect of sodium sulphate in the soil could be entirely eliminated by the addition of an equivalent amount of calcium chloride in accordance with the following reaction :—

$$Na_2SO_4 + CaC_2 \rightarrow 2\,NaCl + CaSO_4.$$

Both sodium chloride and calcium sulphate thus produced are harmless. In the laboratory, it has been found possible to keep a

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soil block containing sodium sulphate entirely free from efflorescence by the addition of calcium chloride. The chemistry of the reaction being so simple, it is an easy matter to determine the amount of calcium chloride required for a particular soil. Another salt which is harmful if present in excess, though not to the same extent as sodium sulphate is sodium carbonate. Fortunately the same treatment with calcium chloride can destroy this salt also.

$$Na_2CO_3 + CaCl_2 \rightarrow 2\ NaCl + CaCO_3.$$

The adverse effect of Na_2SO_4 is due to the formation of a number of hydrates, of these the deca-hydrate $Na_2SO_4 . 10H_2O$ is the most important. The volume occupied by this hydrate produced from a cubic foot of the anhydrous salt is 1·825 cubic feet. Such enormous volume changes disintegrate the soil crust and leave the soil in a loose and fluffy condition. It was noticed that the particles of soil pushed apart by the increase in the volume of sodium sulphate due to hydration do not return to their original position when the salt is dehydrated thus the particles are separated until the maximum possible pore space is reached and the volume changes can be accommodated within that space. The road surface can rise by several inches through this cause if left undisturbed. There is another point worth noting in this connection. Sodium sulphate deca-hydrate when dehydrated by a rise of temperature dissolves in its own water of hydration. The solution thus formed moves towards the surface by capillary action At the surface, the water evaporates leaving the anhydrous salt behind as a loose white incrustation.

There are important differences between soil and sand with regard to the action of sodium sulphate described above. The average diameter of the pores in sand being comparatively large, the hydration and dehydration of this salt can take place within the pore space Even if the particles of sand are pushed apart due to the hydration of the salt, they fall back into their original position on dehydration The movement of the sodium sulphate dissolved in its water of hydration which plays such an important part in soils is also reduced in the case of sand. These differences are of great practical value in checking the movement of salts in the soil by interposing a layer of sand between the salt containing soil and the road surface. Laboratory experiments indicate that a layer of sand as small as one inch placed on a wet soil containing two per cent. sodium sulphate did not allow any moisture or salt to move to the upper layer of the soil. The lower layer of soil was wet even after three months and the upper soil layer did not show any signs of fluffiness.

The practical importance of these results is obvious. A stabilized earth road can be protected from the disintegrating effects of sodium sulphate in the sub-grade by placing it on a carpet of sand. Th

actual thickness of the sand layer suitable for a particular sub-grade has not been worked out under actual field conditions. It is hoped to do so in the next cold weather, when the most suitable meteorological conditions exist for the study of salt movement in the field.

The Influence of Particle Size, Exchangeable Bases and Hygroscopic Moisture on Soil Cohesion.—During the past year investigations have been in progress to determine the factors which affect the quality of earth roads. In the Punjab there is a considerable mileage of earth roads carrying heavy traffic. The maintenance of the roads requires considerable expenditure. A knowledge of the factors which distinguish between a good and a bad road may lead both to improved communications and to a reduction in the cost of maintenance.

Cohesion is one of the main properties upon which the quality of a road depends. Cohesion is the resistance offered by the soil to any force tending to break it. To the clay fraction must be ascribed the cohesion in dry soils. The investigation of the factors affecting the cohesion caused by clay are important.

The magnitude of the force of cohesion must depend on the number of points of contact between the particles. The smaller the size of the particles, the larger will be the number of points of contact in a given weight of soil with the closest packing. An apparatus to measure cohesion was described in the report for 1938.

In order to determine the effect of particle size of the framework material on the cementing action of clay the effect of the addition of increasing amounts of clay on the cohesion of silt and sand was studied. The average diameter of the particles of silt used was 0·0764 m.m. and that of the sand 0·2587 m.m. The results of the tests are plotted in Fig. 5.

It will be seen that the cementing action for a given percentage of clay is greater in the silt-clay mixture than in the sand-clay mixture. This indicates that a soil composed largely of silt is likely to form a better road with the same percentage of clay than one in which the sand fraction is high. The silt and sand contents of roads are, therefore, likely to be important factors determining their wearing properties.

A further important point shown by Fig. 5 is that, beyond a certain amount, further additions of clay do not increase cohesion. This condition appears to be reached when the coarser particles have been completely enveloped in clay and the spaces between the particles filled with clay. If clay is added beyond the amount required for this condition, the larger particles will be pushed apart and cohesion reduced. From these results it would seem that a much larger amount of clay binder will be required for sand than for silt when the

mixtures attain their maximum strength. In order to reduce the amount of clay required for binding, the voids between the larger particles must be filled with smaller ones of gradually diminishing size. It follows that a soil containing particles of various sizes is likely to give a better basic material for roads than a soil in which the individual particle size differs little from the mean.

In order to investigate further the effect of the size of particles on the changes in cohesion on the addition of clay, particles of various sizes were separated by means of the siltometer for the larger sizes and by beaker sedimentation for the smaller sizes. Clay was added to each of these fractions and the cohesion measured. The results obtained are plotted in Fig. 6. It will be seen that the cohesion for the same percentage of clay rapidly decreases as the particle size increases up to a certain point beyond which the effect of the basic particle size becomes negligible.

From these results it appears, therefore, that a good earth road can be expected on a soil composed largely of the finer particles. This finer fraction should itself contain particles with a wide variation in diameters.

Another factor largely affecting cohesion is the moisture content of the soil. The effect of moisture on soil cohesion has been studied chiefly in the wetter regions, where it is entirely accounted for by the surface tension of the liquid films of decreasing thickness which draw the particles closer together. In the region of hygroscopic moisture, drying or wetting leads to very little change in volume of the soil as a whole, so that the limit of compactness has been reached and the particles cannot get any closer together on further drying. This region, therefore, seems to have presented no point of interest and information regarding it is confined to few isolated observations. The enormous change in cohesion due to the drying of the hygroscopic moisture leads one to the conclusion that beyond a certain stage of wetness the cohesive forces in soils are partly molecular and, therefore, may be associated with th[illegible] the clay complex. The influence of [illegible]pic moisture was studied on single [illegible] the exchangeable bases by 0·05 *N* HCl treatment and then adding hydroxides of various metals. The soils were oven-dried and then gradually allowed to take up moisture from atmospheres of different humidities in vacuum dessicators for 72 hours. In the case of Na and Ca, the relation between moisture and cohesion was also studied by gradually drying them. The results are plotted in Fig. 7 from which the following conclusions may be drawn—

(1) The effect of exchangeable bases on soil cohesion is a maximum when the soil is dry. The absorption of moisture leads to a narrowing of the differences due to

ions and becomes negligible when the soil is in equilibrium with an atmosphere of 90 per cent. relative humidity.

(2) The order of cohesion for the dry soil follows the generally accepted order of dissociation for these ions, *i.e.*, Li > Na > K > Mg > Ca.

(3) The relation between the moisture content and cohesion is substantially the same whether the soil is gradually dried or re-wetted.

Measurement of the Capillary Power of Sands and Soils.—In connection with certain experiments on earth roads it became necessary to investigate the grading of sands with reference to the thickness of sand layers which would permit salt-laden water reaching the surface. An apparatus to be described was devised and, on the basis of the assumption that water in the sand behaved similar laws to that in a capillary tube, it has been possible to determine the mean diameters of the sand particles.

The well known formula for the height to which water rises in a vertical capillary tube which is wetted by water and whose lower end is in water is :—

$$h = \frac{4T}{g \rho d} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

where h = height of meniscus above water level.

T = surface tension of water in air.

g = accelaration of gravity.

ρ = density of water.

d = diameter of the capillary tube.

Substituting the numerical values (C.G.S. System) in equation (1) we have approximately

$$h = \frac{0{\cdot}30}{d} \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

Applying this equation to the rise of water in soil, d must be regarded as the equivalent diameter of a capillary tube made up of the spaces between the particles. The relation between d and the diameter of the particles D, has been worked out by Slichter* in the case of an ideal soil, *i.e.*, one having particles of the same diameter. His analysis shows that the value of d at the widest part of the triangular pores between the particles is 0·288 D, where D is the diameter of the

*Slichter, C.S., 1898, Theoretical Investigations of the motion of Ground Water, U.S. Geol. Survey, 19th Ann. Rept. Pt. 2, pp. 301—384

spheres in the ideal soil. The relation (2), therefore, can be written as :—

$$h = \frac{0 \cdot 30}{0 \cdot 288D} = \frac{1}{D} \text{ approximately} \qquad .. \quad (3)$$

In other words, the height of capillary rise is approximately equal to the reciprocal of the diameter of the particles, both quantities being expressed in the same unit.

Description of Apparatus.—The apparatus shown in Fig. 8 consists of a buchner funnel provided with a sintered glass filtering disc. The funnel is joined through a rubber connection to a burette tube that can be raised or lowered against a graduated scale. The entire funnel is filled with water by inserting a rubber bung at the top and joined to the rubber tube leading to the burette. Care is taken that no air bubble is allowed to remain at the lower surface of the filtering disc. Excess of water is removed at the top and a quantity of sand or silt to give a layer of about half a centimetre with some free water standing on top is added. To start with, the level of water on top of the silt and in the bruette tube is the same. The burette tube is lowered in steps of 1 cm. or so and the rise of water noted in terms of the graduations on the burette tube. This rise continues until the free water surface over the sand disappears, and the capillary pull of the water held in the interstices comes into play. From this point onwards, further lowering of the burette tube does not cause any rise in the level of the water contained in it. This constant value continues until the difference of the pressure exceeds the capillary pull of the sand and the water again begins to rise in the burette tube. There is a definite break if the layer of sand is only a few millimetres thick. The water levels in the burette tube are plotted against the scale readings and the vertical portion of the curve represents the capillary pull. Some typical curves are given in Fig. 9 along with the mean diameters of the silts. With the help of the apparatus described, it is now possible to measure the maximum capillary force that can develop in a sand of a particular grade of coarseness and thus test relation (3) between the diameter of particles and the maximum capillary force. A number of sands were examined, the mean diameters of these having been determined from their distribution curves obtained by the siltometer. These values were compared with the values obtained by the apparatus from the relation $h = \frac{1}{D}$, where h is the maximum capillary pull and D the mean diameter of the particles. It will be seen from Table 4 that the agreement between the two sets of values is close. The apparatus can, therefore, be used as a rough and ready method for determining the mean diameter of sands.

Ultra-Clay and the Efficiency of Dispersion Methods.—The efficiency of the preliminary treatment of soils for mechanical analysis is generally reckoned on the basis of conventional clay (0·002 mm). This limiting diameter, though extremely useful as a basis of soil classification, would be considered as referring to very coarse particles, as compared to those of colloidal dimensions. The use of the super-centrifuge has made possible the separation of ultra-clay in which the colloidal properties are much more pronounced. In this study, the size distribution of the finer fractions in the conventional clay has been examined and the manner in which it is affected by the various preliminary treatments of the soil for mechanical analysis and by the nature of the exchangeable ion has been studied.

The following methods of dispersion were tried :—

(1) Na_2CO_3 — NaOH method. Addition of Na_2CO_3 equivalent to the exchangeable Ca in the soil, and NaOH equivalent to the free acidoid.

(2) $(NH_4)_2CO_3$ method. Boiling the soil with *N* ammonium carbonate solution and continuing the boiling after the addition of NaOH or LiOH.

(3) NaCl—NaOH method. Leaching the soil with *N* NaCl following by shaking after the addition of NaOH.

(4) HCl—NaOH method. Leaching with 0·05 *N* HCl followed by shaking after the addition of NaOH.

(5) Alkaline permanganate method. Destruction of organic matter with alkaline permanganate, followed by leaching with oxalic acid and then with dilute H_2SO_4; finally shaking the suspension with the addition of NaOH.

(6) International method. Destruction of organic matter with H_2O_2 followed by leaching with dilute HCl and finally shaking with the addition of NaOH.

The methods outlined above fall into two categories :—the first three depend on the direct replacement of exchangeable Ca by Na without the removal of $CaCO_3$ from the soil. The last three aim at the removal of exchangeable Ca as well as $CaCO_3$, thus converting the soil into an acidoid which is subsequently neutralized with NaOH. It is clear that all the treatments ultimately result in the production of Na soil which is supposed to give maximum dispersion. The choice of these methods is particularly interesting because in the various publications from this Institute, it has already been shown, that they give maximum dispersion on the basis of conventional clay. As the addition of NaOH constitutes an essential feature of every dispersion method, it is desirable to know the exact

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amount of this alkali required in individual cases. It has been shown that the maximum pH at which all soils are completely peptised is 10·8, though some soils show the maximum dispersion at a lower pH value. The failure to recognize this fact has led to the continuance of the search for the ideal method which would give the maximum dispersion with all soils. As a matter of fact, most of the methods would produce maximum dispersion provided care is taken to bring the soils to pH 10·8. In the present investigation this was done in all the methods used.

The ultra-mechanical analysis was carried out on the whole soil with the usual pipette technique in a one per cent. suspension. The soils after the various treatments were made up to a standard volume in bottles of uniform diameter. These were placed in the corner of a room not used for any other purpose and in which temperature variations and other disturbances were a minimum. Temperature variations, however, did exist, but care was taken that no particular soil or treatment received an unduly larger share of any external disturbance likely to occur during the time the suspensions were allowed to settle. It must be admitted that the long time of settling (over 12 weeks for the finest fraction), and pipetting from a particular depth has its objectionable features and for that reason some people might prefer a centrifuge to reduce the time factor, but it must be remembered that a straightforward settling column is capable of theoretical interpretation and practical demonstration. Settling by gravity is also important in maintaining a continuity of the size distribution curve for the whole soil down to ultra-clay. The results of the ultra-mechanical analysis are given in terms of diameters of particles as calculated by Stokes Law from their settling velocities. It is by no means certain that Stokes Law holds for particles of this size. The diameters recorded were not measured directly, but simply assumed in accordance with Stokes Law. The following general conclusions may be drawn from the results of the investigation :—

(1) All methods of treatment give practically the same results as regards conventional clay (·002 mm. diameter).

(2) Methods involving acid treatment give a higher percentage of finer fractions than the others.

(3) Methods involving no acid treatment (1—3) are not able to resolve all these finer fractions into their ultimate units.

(4) It is quite likely that for some soils ultra-clay may be identical with ordinary clay (·002 mm. diameter). There is, however, no doubt that some soils, especially those of allavial origin, do show a stable size distribution of fractions in the region of ultra-clay.

The Expression of the Mechanical Analysis and State of Aggregation of Soils by Single Values.—Sizo distribution curves of soils afford the most comprehensive picture of the mechanical composition of such aggregates. Such curves, though characteristic of different soils, are not convenient for defining soils for purposes of classification. An attempt was made to express tho mechanical composition of soils by "Single values" derivable from tho summation or distribution curves. There are three such values, each characteristic of the shape of the distribution curve, namely, the—

Weighted mean size, M

The standard deviation σ and

The Schoklitsch number or K

Methods of deriving theso constants from the distribution curves are given in a publication of this Institute (Research Publication, Volume II, No. 15).

In dealing with the size distribution of particles in soils it must be noted that the stato of aggregation as it is found in nature may be very different from its ultimate structure. The former denotes tilth, and the latter provides a datum line for expressing the limits of variations in soil texture. The crumb structure of a soil is merely a single phase in its dynamic history, and, therefore, it cannot be used for the textural classification of a soil which must be based on its ultimate structure.

Tilth is a complicated property of the soil, the determination of which would be extremely useful from the practical standpoint. The most logical method of expressing soil tilth would be one based on the entire mechanical analysis of the soil or a function thereof. In other words, tilth or the state of aggregation of a soil must give the existing mechanical analysis of the soil as a function of its ultimate analysis. For this purpose M, K, and σ, which are characteristic constants of any mechanical composition curve, could be used. These values of a soil can be taken before and after dispersion, referred to as M_o, σ_o, K_o and M, σ and K respectively, the latter value referring to the ultimate structure. The ratio of these constants may be related to soil tilth. Which of these ratios is the most suitable from the practical standpoint can then be determined.

Air-dry soils passing a 1—mm. mesh were used for this study. Tho mechanical analyses before and after dispersion were made partly by the pipette method and partly by tho siltometer.

The following general conclusions are drawn as a result of the study :—

Alluvial soils givo a low value of M ($\leq$ 0·05 mm.) a low [illegible] of σ, and a low value of M./M. A low valne of M associated with low clay content (below 20 per cent.) characterizes an alluvial [illegible]

is exactly what one would expect. Such deposits are well-graded (low σ) and silt gradually merges into clay. Their low clay content and high silt content do not lead to the formation of many aggregates, a fact that is borne out by a low ratio.

Black cotton soils (chernozems) have a high clay content, a low value for M, and a high M°/M ratio. These soils present a high state of aggregation and possess a crumb structure that would be associated with good tilth.

Lateritic soils give a high M value and a medium M°/M ratio.

Red ferruginous soils have medium clay, a high M value, a low M°/M ratio, and a high value for σ. These soils, in fact behave like a mixture of fine particles abruptly changing into coarse grains.

K values run almost parallel to M values and therefore are not likely to prove any better than the M values.

The Preparation of a Non-Erodable Mud Plaster.—In the Punjab houses made of unburnt bricks covered with a mud plaster are those normally constructed in the villages. The roofs of houses made of burnt bricks are usually covered with a mud plaster to render them water-tight. During heavy rains the mud plaster is eroded and results in considerable discomfort and expense to the occupants. For some time attempts have been made to produce a cheap plaster out of local materials that would withstand the heavy rainfall.

The experiments were commenced by adding varying quantities of cement to a Punjab soil containing about 15 per cent. of clay. The erodability of these mixtures was determined under standard conditions as described in a previous report. The results showed that the addition of 5 per cent. cement by weight rendered the soil practically non-erodable under the heaviest conditions of rainfall likely to be experienced in the Punjab.

The method was then tested at the field laboratory by erecting mud walls covered with the non-erodable plaster. The field work has now been in progress for eight months and the treated walls have shown no signs of erosion whereas the untreated walls have lost a considerable amount of the mud plaster through erosion by rain. The following is the specification of the plaster and its method of preparation :—

The following quantities of material will be required to cover an area of 1,000 square feet with a plaster 1 inch thick.

75 cubic feet of earth.

25 cubic feet of sand.

4 bags of cement.

4 maunds of straw.

20 lbs. of sodium carbonate.

Dissolve the sodium carbonate in sufficient water to soak 4 maunds of straw, add earth and work it up into a *gara*. Leave this mixture for a week working it up every day and adding sufficient water to make up the loss due to evaporation. After a week the soil will have dispersed completely and the straw will be well rotted. Mix thoroughly 4 bags of cement with 25 cubic feet of dry sand and add to the *gara* working up the entire mass to a suitable consistency and use as soon as possible.

Keeping the relative proportions of the various ingredients constant, the quantity of the mud plaster can be varied to suit individual requirements such as the area to be plastered and the thickness of the plaster. For ordinary plastering of kacha walls and roofs a layer of ½ inch is quite sufficient. For plastering watercourses or tanks for storing water a layer 1 inch thick is recommended.

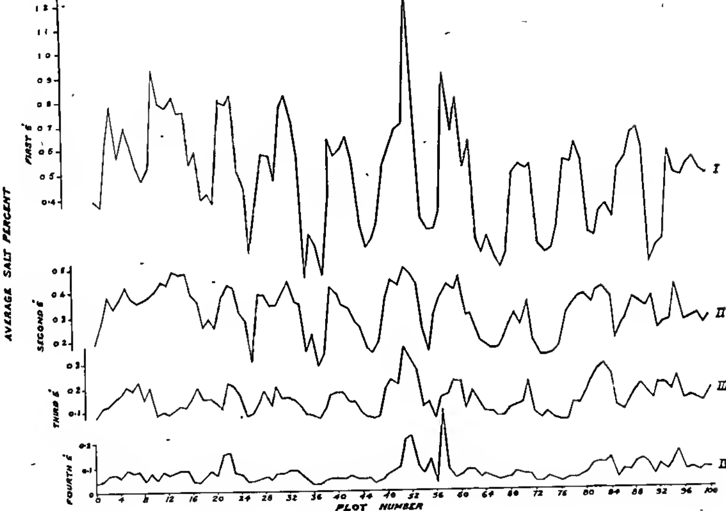
TABLE 4.

Mean Diameter of silts by two methods.

Capillary column cm.	Mean diameter in mm.		Capillary column cm.	Mean diameter in mm.	
	Siltometer.	Capillarimeter.		Siltometer.	Capillarimeter.
35·6	·230	·231	20·0	·501	·500
49·0	·205	·204	18·9	·493	·529
44·0	·189	·227	19·6	·483	·505
43·5	·226	·230	21·0	·476	·476
83·5	·126	·120	20·6	·467	·485
78·4	·129	·127	23·4	·441	·427
78·0	·131	·123	22·1	·432	·452
57·5	·136	·148	25·5	·403	·392
69·0	·151	·145	26·8	·388	·373
67·2	·172	·175	28·4	·380	·352
59·2	·178	·169	29·8	·345	·340
51·6	·208	·194	31·6	·338	·317
61·7	·197	·162	33·2	·325	·301
46·3	·202	·216	33·0	·320	·303
67·4	·159	·148	41·3	·288	·242
41·2	·250	·242	49·0	·255	·204

TABLE 4—CONCLD.

Capillary column cm.	Mean diameter in mm		Capillary column cm.	Mean diameter in mm.	
	Siltometer	Capillari-meter.		Siltometer.	Capillari-meter.
79·7	·133	125	28·0	·381	·357
50·6	·204	·198	26 5	·355	·377
29·3	340	·341	36·2	·278	·276
30·5	·363	328	38·0	2737	·263
29·3	·369	·341	36 0	·274	·278
32·2	313	311	32·7	·350	306
44·7	·242	223	32 0	·353	313
45·3	·205	220	17 5	·711	·571
35·7	·306	281	21 4	·646	·458
42·1	·225	234	17·8	·636	·505
43·7	·227	·229	17 6	·624	667
34·0	·270	·294	44·6	·231	224
27·2	·357	·367	31·3	·332	·319
48·0	215	·208	41·4	·227	·242
43·5	·201	220	66·4	·141	·161
40·6	·261	·246	94·3	·117	·106
37·7	·245	·265	56·9	·166	·172
40·8	·250	·240	55 5	·185	160
35·0	·283	·284	55 3	·188	181
28·8	351	·347	52·5	·201	·190
39·0	·263	·256	46 4	216	·215
28·8	·338	·347	64·3	·179	·155
24·7	·332	·409	47·1	·223	·212
19·8	·512	·505	42·7	·147	·234
			54·7	·181	·183



AVERAGE SALT PERCENT
FIRST 6"
SECOND 6"
THIRD 6"
FOURTH 6"
I
II
III
IV
PLOT NUMBER

FIG.2

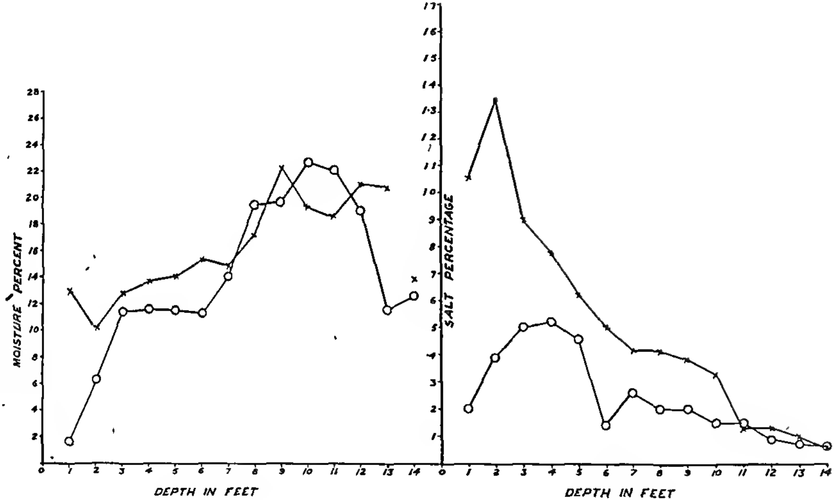

MOISTURE PERCENT
DEPTH IN FEET
SALT PERCENTAGE
DEPTH IN FEET

FIG.2

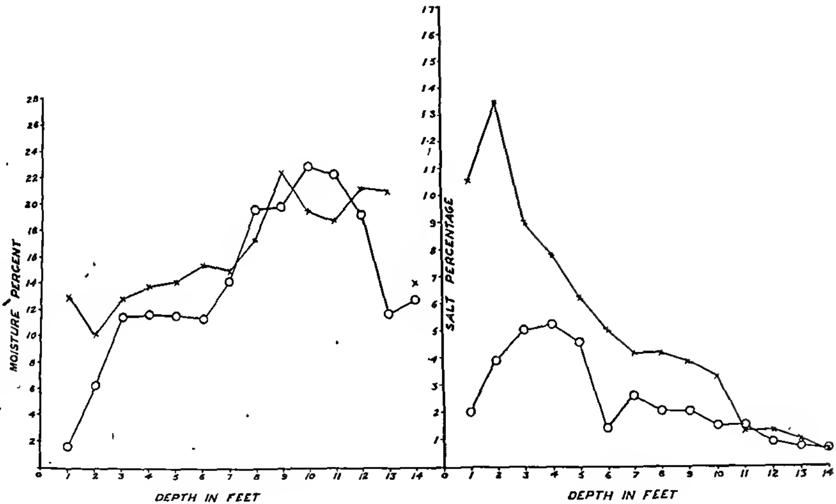

MOISTURE PERCENT
DEPTH IN FEET
SALT PERCENTAGE
DEPTH IN FEET

FIG.3

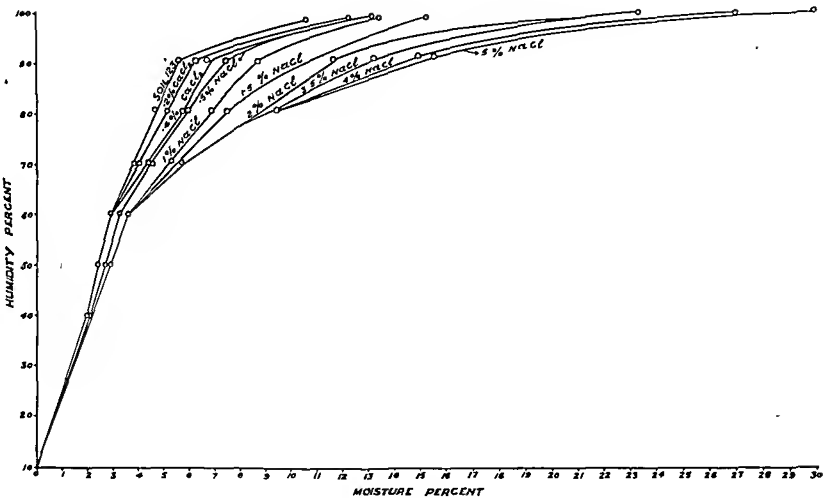

HUMIDITY PERCENT
MOISTURE PERCENT
1% NaCl
2% NaCl
4% NaCl
5% NaCl

FIG.3

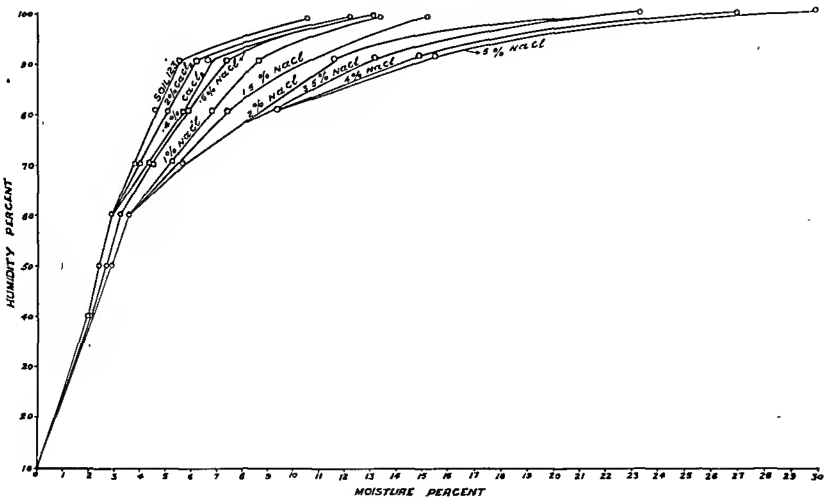

HUMIDITY PERCENT
MOISTURE PERCENT
SOIL 123
2% cacl
cacl
.8% nacl
1% nacl
1.5 % nacl
2% nacl
3.5% nacl
4% nacl
5 % nacl

FIG. 4

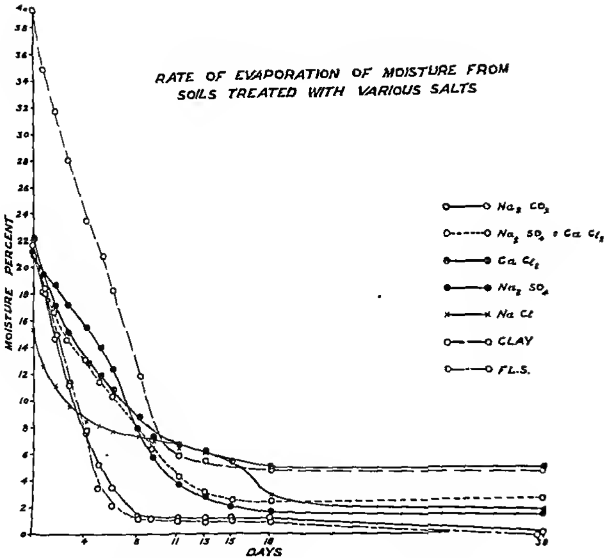

RATE OF EVAPORATION OF MOISTURE FROM SOILS TREATED WITH VARIOUS SALTS
Na_2CO_3
Na_2SO_4 + $CaCl_2$
$CaCl_2$
Na_2SO_4
$NaCl$
CLAY
FL.S.
MOISTURE PERCENT
DAYS
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
4
8
11
13
15
18
38

FIG. 5

RELATION BETWEEN COHESION AND CLAY IN SILT AND SAND

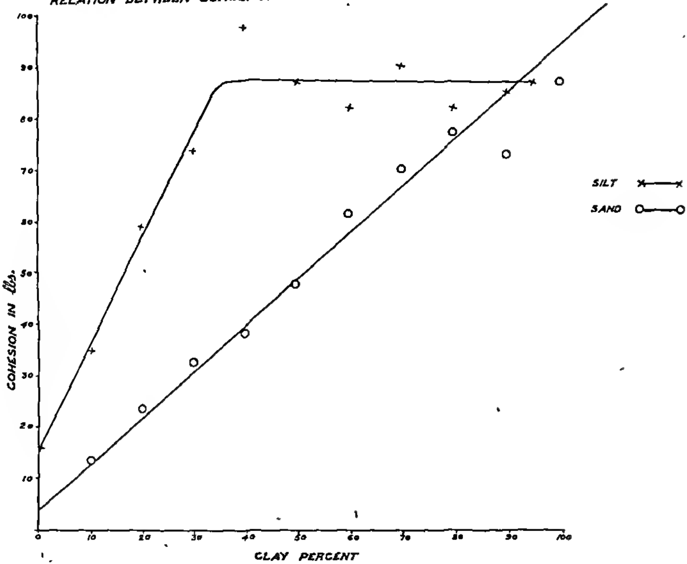


FIG. 6

EFFECT OF SIZE AND PERCENTAGE OF PARTICLES (SAND) ON COHESION OF CLAY SOIL

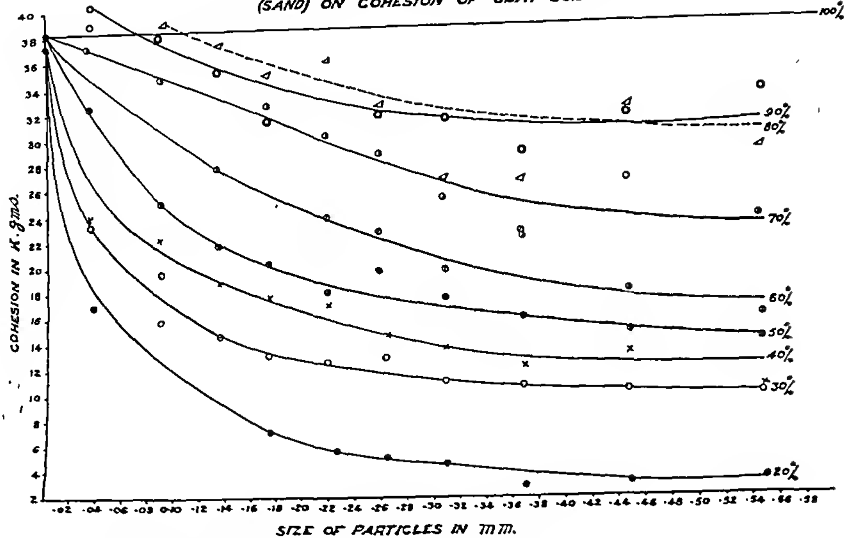


FIG. 7

EFFECT OF MOISTURE ON COHESION IN VARIOUS ION SOILS

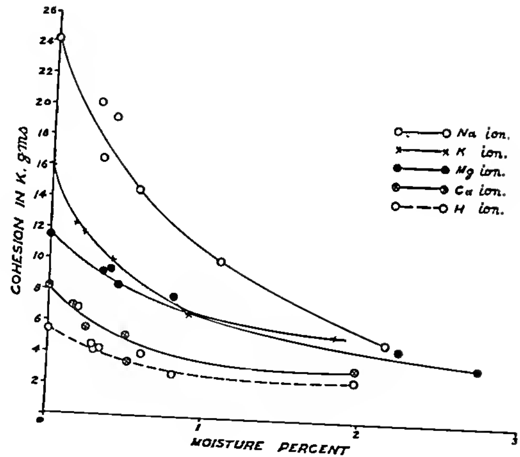


FIG. 6

APPARATUS FOR MEASURING CAPILLARY FORCE OF SAND

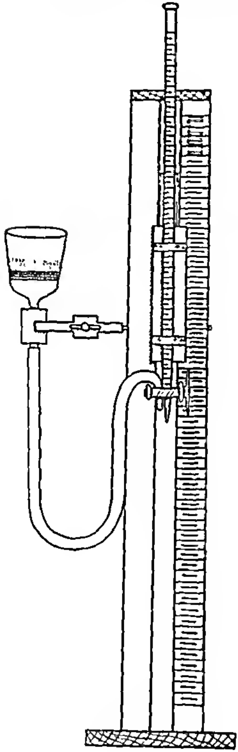
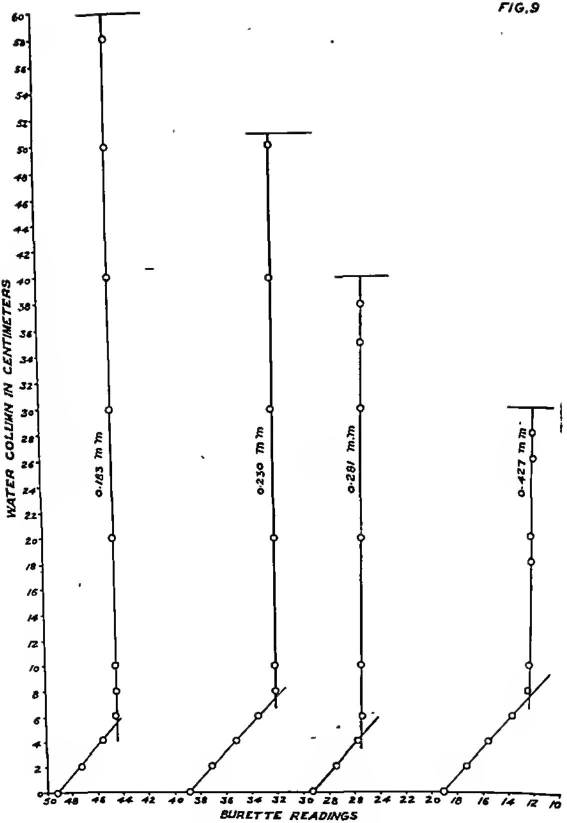


FIG. 9



WATER COLUMN IN CENTIMETERS
BURETTE READINGS
0·183 m m
0·230 m m
0·281 m m
0·427 m m

PHYSICS SECTION.

The experiments on models of tube-wells reported last year have been continued especially with reference to the effect of the boundary conditions on the results. The original experiments were carried out in a small tank. This year they were repeated in a tank of 180 × 65 × 35 cms. which enabled a greater variation in the conditions to be examined. The strainer was, as before, a perforated sheet cut to a semi-circular section. The front of the tank was of glass to enable the water level in the strainer to be observed.

The experimental technique was also improved; temperature variations were eliminated so far as possible, and difficulties due to the presence of air bubbles were overcome. A double-walled tank, in which the water was allowed to stand for 48 hours before use in experiments, was constructed. The water was filtered through glass wool to remove the small quantities of suspended matter which are usually present.

Relation between Yield and Drawdown.—It has been generally accepted that the yield of a tube-well bears a linear relationship with the drawdown. An investigation of this point over as wide a range as possible seemed desirable.

The results obtained are shown in Figs. 10, 11 and 12. Referring to Fig. 11, it will be seen that the yield-drawdown curve is convex to the drawdown axis. This indicates that when the drawdown is large, the yield is greater than would be expected according to a linear relation. In the experiments referred to in Fig. 10 the depth of water in the model of the well is 12·7 cms. and the drawdown is about four times the depth of water in the well. This condition does not occur in the field.

From Figs. 11 and 12 it will be seen that the convexity referred to in Fig. 10 disappears gradually. In Fig. 12 the curve is almost a straight line. In the case of Fig. 11, the drawdown is about twice the depth of water in the well and in Fig. 12, the drawdown is nearly equal to the depth of water in the well.

The experiments thus show that the linear relationship between yield and drawdown only holds good when the drawdown approaches a depth equal to or is less than the depth of water in the well. In the field, the drawdown is always smaller than the depth of water in the well and, therefore, the yield is proportional to the drawdown.

The Relation between the Diameter of the Strainer and the Yield of the Tube-well.—It has been generally accepted that the yield of a tube-well is proportional to the surface area of the strainer and, therefore, to the diameter of the strainer. Two sets of experiments were carried out to examine this point.

In the first set of experiments, strainers of 5, 7·5, 10, 12·5 and 15 cms. were used with four different drawdowns. The results are shown in Fig. 13.

It will be seen from the results that the increase in discharge with increase of the diameter of the strainer is small. The discharge increases with the drawdown but as previously mentioned other factors operate at larger drawdowns. For practical purposes, small drawdowns only need be considered. As an example, for a drawdown of 10 cms. an increase of diameter of the strainer from 5 cms. to 15 cms. only increases the discharge by 21 per cent. The increase in discharge with increase in diameter of the strainer is given in Tables 5 and 6.

TABLE 5.

Initial diameter.	Final diameter	Discharge with 5 cm strainer	Discharge with 15 cm. strainer.	(h) Depth of water in the well.	(H—h) Draw-down.	Relative Discharge.
cm.	cm.	c. c./sec.	c. c./sec	cm.	cm.	
5	15	16 0	19 5	30·48	10	1 . 1·21
5	15	25 8	32 5	30·48	15	1 : 1·25
5	15	37 5	49 0	30 48	20	1 : 1·28
5	15	50 5	63·5	30·48	25	1 : 1·25
5	15	30 2	37·8	35 48	15	1 : 1·25
5	15	42 8	54 5	35 48	20	1 : 1·27

TABLE 6.

Initial Diameter.	Final Diameter.	Discharge with 5 cm. strainer.	Discharge with 15 cm. strainer.	(h) Depth of water in the well	(H—h) Draw-down.	Relative Discharge.
cm.	cm.	c. c./sec.	c. c./sec.	cm.	cm.	
5	10	16·0	17·8	30·48	10	1 : 1·11
5	10	25·8	28·8	30·48	15	1 : 1·11
5	10	37·5	43·2	30·48	20	1 : 1·15
5	10	50 5	56·0	30·48	25	1 : 1·11
5	10	30·2	33·0	35·48	15	1 : 1·11
5	10	42·8	45·7	35·48	20	1 : 1·11

In these experiments the strainers have been varied from 5 cms. to 15 cms. as in practice strainers of 3 inches to 6 inches are most commonly used. The conclusions reached, therefore, only apply to the range of diameters investigated.

The general belief that the discharge of a tube-well is proportional to the surface area of the strainer is not supported by these experiments.

The relation between Yield and Shrouding.—In carrying out the experiments to examine this point, a strainer of 15 cms. in diameter was used and the entire length of the strainer was shrouded. For comparison, in the first set of readings the space between the sand and the strainer was left without shrouding so that it actually represented a strainer with the diameter of the tube-well together with the shrouding. In the other experiments the shrouding material consisted of sand between (1) 2·5 and 3·5 mm., (2) between 0·5 and 1·0 mm., and (3) with the sand forming the water-bearing medium. This latter sand had a diameter of 0·5 mm., its distribution curve is given in Fig. 14. Photomicrographs of the shrouding materials are given in Fig. 15.

The discharges obtained with the various shrouding materials are shown in Table 7.

TABLE 7.

Nature of shrouding space.	*Discharge.*
Empty	97·8 c. c./sec.
Sand sieved between 2·5 and 3·5 mm.	96·8 c. c./sec.
Sand sieved between 0·5 and 1·0 mm.	88·6 c. c./sec.
Original sand	60·3 c. c./sec.

The results show that for a sand stratum of mean diameter 0·5 mm., the critical shrouding material is between 2·5 and 3·5 mm. If the shrouding material is finer, the maximum discharge possible will not be obtained. It is also seen from the table that no advantage will be gained by using a coarser shrouding material since there is little difference in discharge between the 2·5—3·5 mm. shrouding and the absence of shrouding material between the sand and the strainer. This is to be expected since the main resistance to flow into the well is from the water-bearing sand.

In the field, strainers are situated in different strata and, therefore, it is not possible to decide on the size of the shrouding material for a well as a whole. For shrouding tube-wells in the usual water-bearing sand of the Punjab a grade of 3·5 mm. will probably be found to be most satisfactory.

Discharge of a Tube-well with reference to the position of a strainer in relation to that of an impermeable stratum.—The effect of the position

of the strainer with reference to an underlying impermeable stratum has also been studied. The problem may be stated thus—if a unit length of strainer is placed in a permeable stratum of large depth, will the discharge be the same as though the depth of the stratum is limited to the length of the strainer, all other conditions remaining the same.

The experiments were carried out with a strainer of 20 cms. in length, its position being altered as shown in Fig. 16. The positions of the strainer were raised in steps of 5 cms. Four sets of observations were taken with different drawdowns.

It will be seen from Fig. 16 that the discharges are affected by the proximity of an impermeable boundary. In the cases referred to in Fig. 16, the discharges increase when the strainer is moved away from the impermeable stratum. In this case again the rate of increase is larger for larger drawdowns; thus, for the same change of position the increase in discharge for a drawdown of 25 cms. is from 39·6 c.c./sec. to 55·3 c.c./sec., whereas for a drawdown of 10 cms. the corresponding increase is from 13·4 c.c./sec. to 16·5 c.c./sec.

The main reason for the increase in discharge when the strainer is away from an impermeable stratum is, that if the water-bearing sand is bounded by impermeable strata, the number of streamlines that can converge to the tube-well is limited, whereas in an unlimited boundary, this is not the case. When the drawdown is small, this convergence towards a strainer decreases and so the streamlines become more and more parallel.

Summary of the Conclusions.—As a result of these experiments on models the following conclusions were drawn :—

(1) Under the conditions in the field, the yield of a tube-well is proportional to drawdown. If the strainer length is short and the drawdown large, this relation will not hold, but this case does not occur in practice.

(2) The increase in yield of a tube-well is not proportional to the surface area of the strainer as was generally accepted; the yield increases very slowly with increase in the diameter. Within the ranges of 5 to 15 cms. of diameter investigated, the discharge increases by 10 and 25 per cent. as a result of increasing the size of the strainer two and three times in diameter respectively.

(3) Shrouding may be employed as an alternative method for increasing the diameter.

(4) Equal lengths of a strainer are more effective if they are placed away from an impermeable stratum, *i.e.*, if they are situated in deep and continuous permeable strata, they are more effective than if they are situated in short permeable strata bounded by impermeable layers.

Investigation of the Transmission Constant of Sands from Karol and Western Jumna.—Another problem which arose in connection with the sinking of tube-wells was, which strata were suitable for strainers and what was the permeability of each of these strata. This, in fact, is the most important problem for designing tube-wells.

Trial bores were, therefore, made in the field and samples were sent to the laboratory to determine the transmission constants. There were two projects, namely, one near the Western Jumna in Karnal and Abdullapur districts and another in Karol near Lahore. One thousand samples were received from these two projects.

The method employed to determine the transmission constant has already been described in previous reports. As a result of investigations it was found that values of the transmission constant of 0·00012 ft. sec. and above were suitable for introducing strainers. The transmission constants of the various samples were determined. When the transmission constant of each of the strata of a trial bore has been determined, the results were plotted as is shown in Figs. 17 and 18. Now referring to Fig. 17, it will be found that in the well No. 1 of Karnal group, there are no strata which are suitable for a strainer up to a depth of 125 feet. There is a stratum from 130—150 feet which is just on the marginal value for introducing a strainer. There is another stratum between 210—230 feet which is good. Below this, except for small depths of strata at 280 and 320 feet depths, there are no strata of the required value of the transmission constant, the transmission constants being too low. This bore therefore is not suitable for a tube-well, the yield would be too low, because of the low permeability of the sands.

Figure 18 is for the case of tube-well No. 14, from Karol Project. It will be seen that the transmission constants of the samples are very high and it was possible to obtain a strata of 100 feet suitable for strainers by boring to 260 feet. The boring was therefore stopped at this depth and the tube-well was designed. This particular well gave a discharge of 1·75 cusecs for a 10 feet depression head in the field. Twenty-two wells were examined during the year under report and the results were sent to the Officer on Special Duty. The tube-wells have been designed according to the data.

of the strainer with reference to an underlying impermeable stratum has also been studied. The problem may be stated thus—if a unit length of strainer is placed in a permeable stratum of large depth, will the discharge be the same as though the depth of the stratum is limited to the length of the strainer, all other conditions remaining the same.

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Investigations on Cavities under Weirs.—During the current year an important investigation has been started for detecting imperfect contact of the floors of weirs with the sub-soil. The method depends on the principle of the seismograph. The floor in question is given an artificial impact and the vibrations are recorded photographically. It was expected that the amplitude of the vibrations would enable an opinion to be formed of the nature of the contact of the floor with the underlying sand.

The arrangement of the apparatus is shown in Fig. 19. In the figure L_1 and L_2 are two lenses and S is a source of light. The vibrometer for detecting the vibrations and the camera for recording them are shown in the figure. In the experiments, the vibrations were produced with the help of an eccentric motor, which gave continuous impacts on the floor.

To begin with, experiments were performed on the ground floor of the Research Institute, which is a thin concrete floor on bricks and then on the first floor. The results showed that the amplitude of the vibrations on the first floor which is not in contact with the sub-soil was much larger than that on the ground floor for impacts of similar intensity.

The results being encouraging, it was decided to test the apparatus on a cement block embedded in the ground and try the experiment with artificial cavities under the block. A block of 6 × 6 × 2 feet was built for the purpose and placed well in contact with subsoil. Photographs were taken as described before. An artificial cavity was then made, about 3 cubic feet of sand being taken out from underneath the block. When similar impacts were given and recorded, it was again found that the amplitude had increased.

It was then decided to perform experiments on the downstream floor of Bay No. 3 of Merala Weir. This necessitated certain modifications of the apparatus. These having been carried out, the apparatus was taken to Merala and one set of experiments was made on the reconditioned floor which was known to be sound. An artificial cavity was then made by taking out 6 cubic feet of sand from underneath the floor. When photographs were again taken, it was found that there was no difference in the amplitude between the sound and excavated portion. This was possibly due to the fact that the floor was four feet in thickness and reinforced. The experiments at Merala could not be continued due to the fact that water rose on the downstream floor.

The experiments [illegible] Weir. Experiments [illegible] constr[illegible] of new. [illegible] ts partly of old Fig. 20 shows the plan of the holes with respect to the old and new construction, indicating the positions

of the holes where the experiments have been made. It will be seen that three of the holes investigated are situated in the old construction and four of them are located in the newly constructed portion. The photographs were taken over these seven holes both before and after grouting. These are shown in Figs. 21 and 22. The numbers marked against the photographs correspond to those of the holes given in Fig. 20. "a" refers to photographs taken before grouting and "b" to those after grouting with sand. The quantity of sand grouted into each of the holes is given below:—

Hole No.	*Sand.*
1	7 cubic feet.
2	8 " "
3	1 " "
4	1·3 " "
5	1·3 " "
6	1·3 " "
7	2·0 " "

It will be seen from a study of the photographs that the amplitude of vibrations has decreased after grouting in the case of holes Nos. 1 and 2, but no difference is noticeable for the remaining holes. It appears that the apparatus in its present form is able to indicate a difference when the cavity under the floor is fairly large. It was intended to continue the experiments in Bay No. 7, but the rise of the river prevented further work. This will be continued next winter.

Investigations on Negative Pressures in Soils.—During certain discussions on the rise of water-table and its possible control by surface evaporation, it became necessary to carry out a systematic investigation on the negative pressures developed by the moisture films in contact with the soil particles. The fact that experiments were begun on this subject was reported last year. During the year under report the investigations were continued and twelve specimens of sand and soil were investigated.

The details of the method and the diagram of the apparatus are given in the report for the last year. In that apparatus water was used as the liquid in the manometer. In the case of fine silts and silts mixed with clay, the negative pressure developed is high and so a mercury manometer inclined to the vertical at an angle of 60° and for still finer soils a vertical manometer had to be employed.

Twelve samples of graded sands and natural soils were investigated. Each of these samples was photomicrographed and these

are shown in Fig. 23. The negative pressnree developed by thes samplee are given in Table 8 :—

TABLE 8.

Sample No.	*Negative Pressure.*	*Moisture percentage saturated soil.*
1	11·8 cm. of wator	21
2	15·2 ,, ,, ,,	22
3	24·1 ,, ,, ,,	23
4	36·4 ,, ,, ,,	24
5	49·2 ,, ,, ,,	24
6	72·9 ,, ,, ,,	25
7	86·8 ,, ,, ,,	24
8	181·5 ,, ,, ,,	24
9	200·7 ,, ,, ,,	38
10	313·9 ,, ,, ,,	39
11	391·2 ,, ,, ,,	35
12	562·1 ,, ,, ,,	48

It will he seen from Tahle No. 8 and Fig. 23 that ae the partioles of eoil get finer, the negativo pressure increases. These negative pressures are determined at a stage when the gravitational water has just heen removed and the moisture films are being formed, that ie to say, at a etage of passing from the pendular to the funicular stage. Even at thie high stage of moisture content, as is shown in column 3 of Tahle 8, tho negative pressures developed are fairly high. Another important point to he noticed here is that in finer silts and soils, the negative pressure is developed at a moisture content which is much larger than in the coarser samples. This fact is of importance becauee it explains why the finer soils are ahle to retain more moisture than the coareer under eimilar field conditions. If a high negative pressure is developed, the vapour pressure should be comparatively low; this will canse less evaporation as is found to be the case in finer soils. Another question which arises as a result of this investigation is that, if such large negative pressures are developed in the aggregates of soil particles when any plain water surface in contact with them is destroyed, what will he the effect of these negative forces on any free water-tahle which occnrs in their neighhourhood. In other words, in a field, will the concave menisci and the consequent negative pressure have an effect on the levol of wator in a well sunk in the area. Thie qnestion led to an important investigation in suhsoil physics carried out during the current year that is describea at some length in the following section.

Capillarity and Subsoil Water-Table.—As was indicated in the previons section tho pressure in a capillary fringe is helow the atmospheric pressure, the amonnt of deficiency depending on the curvature

of the surface of the fringes. Any factor which tends to increase this curvature will increase the negative pressure and any factor that reduces the curvature will decrease the negative pressure.

Above the capillary fringe is situated a soil zone in which the water is held to the soil particles in the form of films by the action of surface tension. In this region again the curvature of the films determines the pressure deficiency. In this zone, the radius of the films between the particles varies very rapidly as the surface is approached and as a result there is a steep moisture and pressure gradient.

Thus in any soil profile containing a water-table there are three zones, namely—

(1) A zone completely saturated with water, the water being only under gravitational forces.

(2) A zone completely saturated with water, but held by the capillarity and exhibiting a pressure deficiency, the pressure deficiency being determined by the curvatures of the surface films which are situated in a horizontal plane.

(3) A zone in which air and water are present and in which the water is held in the form of films round the soil particles by the forces of surface tension. The pressure deficiency in the soil increases as the surface is approached owing to the radius of the films decreasing as the moisture content decreases.

The generally adopted method of recording the level of a water-table is by observing the water level in wells or in specially constructed bore-holes. During a dry period the water-table, as indicated by the level of the water in the wells or bore-holes, falls, but after a small shower of rain or after irrigation a rise in water-table considerably greater than can be accounted for by the water applied to the surface takes place. So far no satisfactory explanation of this phenomenon has been given. During the past year a study has been in progress with the object of obtaining a satisfactory explanation.

A circular tank four feet in height and three feet in diameter was filled with water in which sand was deposited so as to obtain a sand saturated with water. An observation pipe fitted with a strainer was attached to the tank so that movements of the water level in the sand could be observed. After the tank had been filled with sand and water, water was drained from the tank and the level of the water in the observation pipe recorded. The immediate resting level of the water in the observation pipe is the level of the water-table in the sand. The arrangement is shown in Fig. 24.

climate, including rainfall and factors determining rainfall, may prevent their use for making quantitative comparisons. Again, an attempt has been made to compare the losses from canals due to seepage with additions to the water-table indicated by well measurements with the object of showing that the prevention of seepage from canals will result in stability of the water-table. If well levels recorded only variations in the water-table, this would be a sound approach to the quantitative side of the problem. It has been shown, however, that well levels as at present observed record pressure deficiencies and, hence, they cannot be used in the quantitative manner that has been attempted. Further work is in progress and the whole subject will later be reviewed.

Rate of Evaporation from a Soil Surface within the Capillary Fringe.—Experiments were carried out to determine the rate of evaporation from sand and soil surfaces under atmospheric conditions within the capillary fringe. Opinions have been expressed that evaporation is likely to be larger from sand and soil surfaces because of the larger area exposed. This is contrary to experimental observations in the past and further experiments were required to elucidate this under local conditions.

The experiments were carried out as follows:—

A number of glass tubes of diameter 2·25 cms., provided with parallel side tubes of diameter 0·5 cms. were filled with saturated sands of various grades, and supported in rectangular wooden stands such that they could be easily weighed by means of a balance. Evaporation under atmospheric conditions was allowed to take place. The level of water in the side tubes and the weights of the tubes were noted at intervals. Simultaneous readings of room temperature and humidity were taken. The relation of changes in water level in the side tubes was plotted against the amount of water evaporated in the corresponding interval. One of the curves is shewn in Fig. 25. This shows a series of steps. Another set of observations was taken with increasing moisture and similar curves were drawn, a specimen curve for the same sand being shown in Fig. 26. This is a straight line. At first, the steps in the first curve were attributed to condensation of atmospheric moisture on the sand at night when the temperature was low (the steps correspond to intervals at night) but later on they were found to be due to the hygroscopic character of the glass. A glass tube was found to vary in weight at different temperatures and humidity, the change being up to a range of 1·0 gram. The experiments were then repeated with brass tubes but these, due to the oxidation of the surface, caused small changes in weight thus vitiating the experiment. Taking into account these disturbing factors, the general curve in the capillary fringe may be taken to be linear. This conclusion is supported by experiments with increasing moisture content.

In all experiments it was fonnd that the fall in water-level in the side tubes in any interval was much greater than what could be accounted for by merely taking into account the amount of water evaporated and the area of cross section of the main tube. For instance, the fall in level in a certain interval in a fine sand was 2·0 cm. while from the amount of water evaporated, a fall of 0·17 cm. could only be accounted for by taking into account the pore space of the sand and the area of cross section of the tube. Thus the actual fall in level was twelve times that which should have occurred on the old hypothesis. Using a smaller side tube the ratio was increased to 25.

Further work is in progress.

Examination of the side Slopes of Drains.—A knowledge of the slope which any particular soil can stand under the lateral pressure of inflowing water is of considerable importance in the design of drains. Without a previous examination of the soil, a drain may be dug through an unsuitable locality resulting in faulty functioning and expensive maintenance.

Information regarding the stability of side slopes of some of the existing drains was sought during the year under report.

The Executive Engineer, Phalia Division, observed that the sides of the Link Drain between the Bahauddin and the Haria Drains did not stand. Samples of soil were taken from the various sites shown in the index plan in Fig. 27. The results of analysis of these samples are given in Table 9.

TABLE 9.

Mechanical Analysis of Soil Samples from Bahauddin—Haria Link Drain.

R. D. of Drain.	Percentage.				
	Coarse sand.	Fine sand.	Silt	Fine silt.	Clay.
25,000	0·67	66 68	20·45	6·10	6·78
26,000	1·09	69·83	17·32	11·60	5·48
27,000	2·71	18·12	27 62	36·20	16·40
29,000	1·05	69·41	12 90	9 60	5·88
31,000	1·11	84·36	6·60	3·70	4·43
34,000	78·48	13·90	3·95	0·83	0·35
37,000	80·07	12 84	3·27	0·28	0·80
40,000	80·80	13 19	2·67	11·52	0·38
43,000	62·11	15·24	2·85	12·25	2·73
46,000	1·31	13·43	12·45	41·30	28·13
49,000	13·78	31·16	17 75	18·82	14·45
52,000	83·92	11·15	0 27	2·20	0·78
55,000	89·53	9 88	0·30	0·70	0·48

It will be seen that most of these samples contain very little of clay the presence of which, in reasonable proportions, is essential for producing the necessary cohesion in the soil. The sides, as it is, could be expected to stand a slope of 1 : 3 but with the subsoil pressure due to the close proximity of the Lower Jhelum Canal, it was considered doubtful whether it would stand at 1 : 6. Under such conditions the cost of maintenance on this drain was expected to be prohibitive.

The Wan Drain, the Nahi Shah Jhil Drain, and the Mona Drain were also similarly examined.

A general study of the stages through which the sides of a drain pass in the process of sloughing in, are illustrated in Fig. 28. The photograph marked No. 1 shows the stable side of a drain. Photograph No. 2 shows the beginning of the effect of rain and seepage through the sides as a result of which furrows make their appearance. Caving in at the lower end has commenced in the next and has extended in photograph No. 4. This stage precedes the falling in of the whole super-incumbent mass of earth into the drain, which is shown in the photograph No. 5.

Electrical Gauge for Khanki.—It was reported last year that an investigation had been started to devise an electrical gauge capable of being read at a distance from the gauge-well at Khanki. This apparatus was installed at Khanki headworks. While its working was satisfactory, it was found difficult to keep the batteries of the gauge in a fully charged condition. It was, therefore, thought advisable to make the gauge readings independent of the voltage of the battery.

Further improvements were therefore effected in the gauges. The improved gauge works on the wheatstone bridge principle and is, therefore, independent of the voltage of the battery. Two such gauges are under preparation in the laboratory and will be installed at Khanki as soon as they are completed.

Investigations on Silt.—The mechanical analysis of the silts for the study of regime conditions was continued during this year. One thousand and four hundred samples were analysed and the data submitted to the Mathematical Section which is dealing with the further aspects of the problem.

FIG. 10

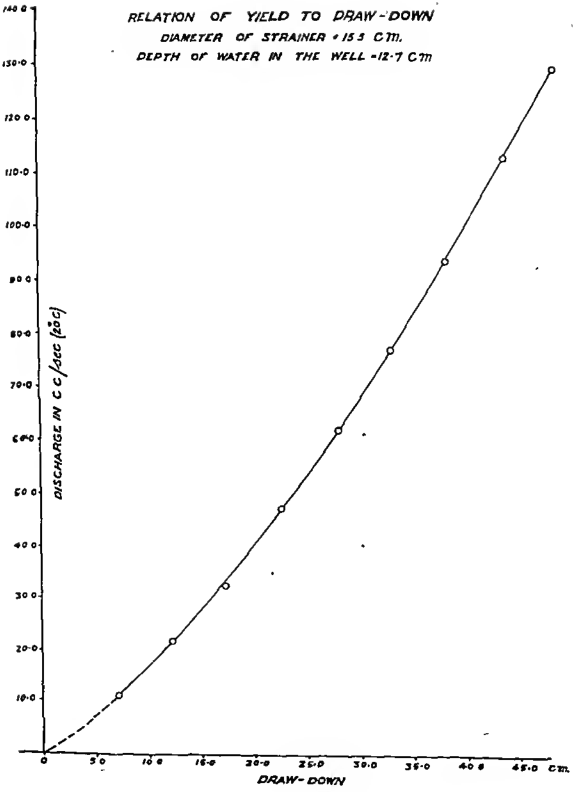
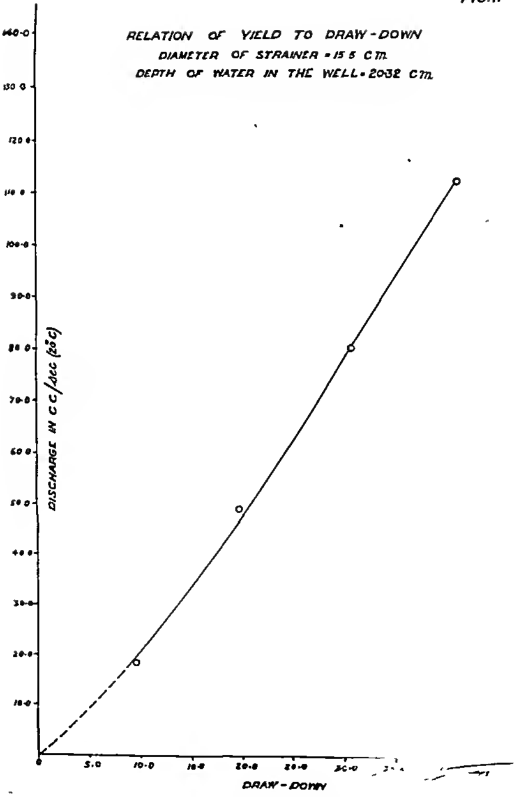

RELATION OF YIELD TO DRAW-DOWN
DIAMETER OF STRAINER = 15.5 Cm.
DEPTH OF WATER IN THE WELL = 12.7 Cm
DISCHARGE IN C.C/SEC (20°C)
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
45.0 Cm.
DRAW-DOWN

FIG. II



RELATION OF YIELD TO DRAW-DOWN
DIAMETER OF STRAINER = 15.5 Cm.
DEPTH OF WATER IN THE WELL = 20.32 Cm.
DISCHARGE IN C.C./SEC (20°C)
DRAW-DOWN

FIG. 12

RELATION OF YIELD TO DRAW-DOWN
DIAMETER OF STRAINER = 15.5 Cm.
DEPTH OF WATER IN THE WELL = 30.5 Cm.

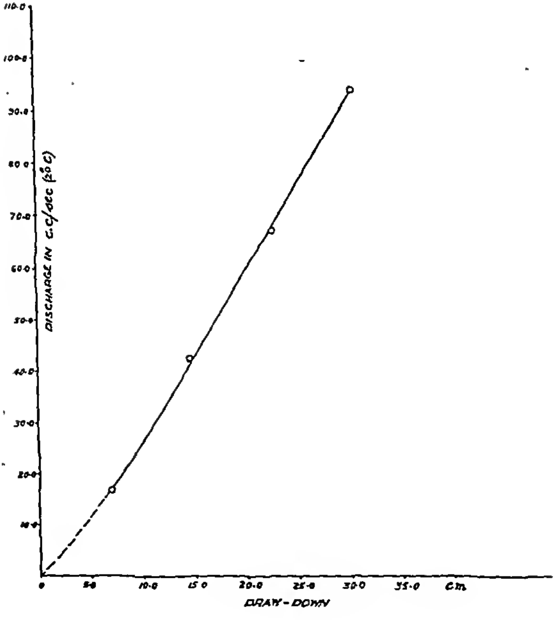


FIG. 13

RELATION BETWEEN YIELD AND DIAMETER

DEPTH OF WATER IN WELL = 30·48 CM.

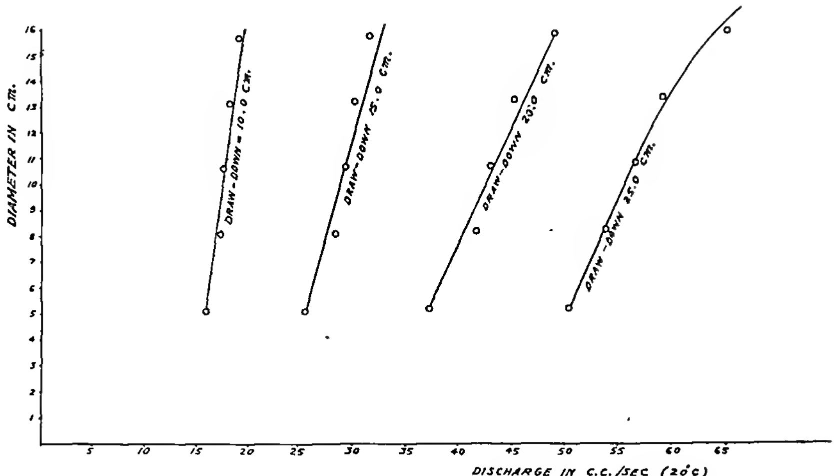


FIG.14

II SAND USED FOR TUBE WELL

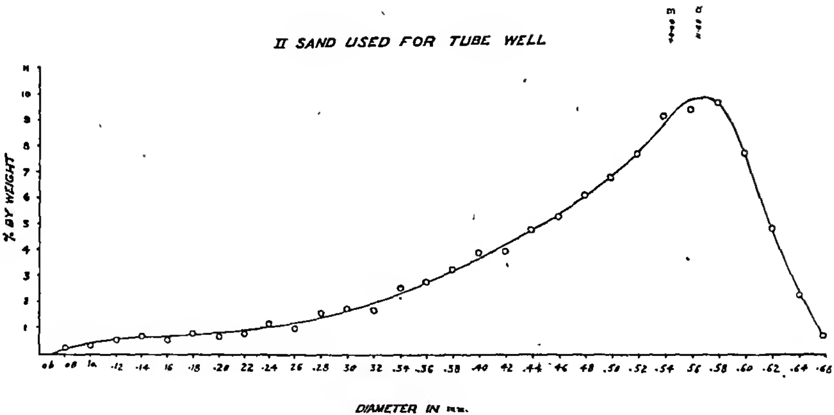


Fig. 15.

PHOTOMICROGRAPHS OF SAMPLES USED FOR SHROUDING.

Linear Magnification 1 : 4.

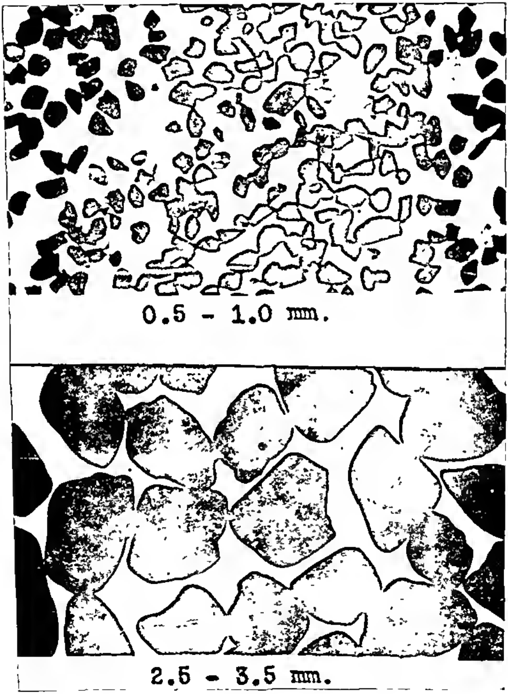


FIG 16

DISCHARGE IN RELATION TO POSITION OF STRAINER AND THAT OF AN IMPERMEABLE STRATUM

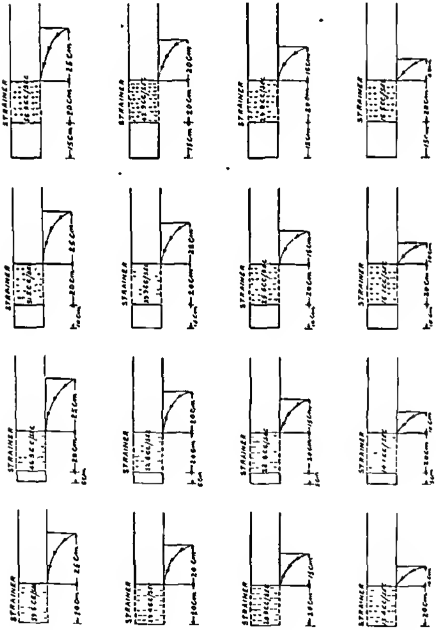
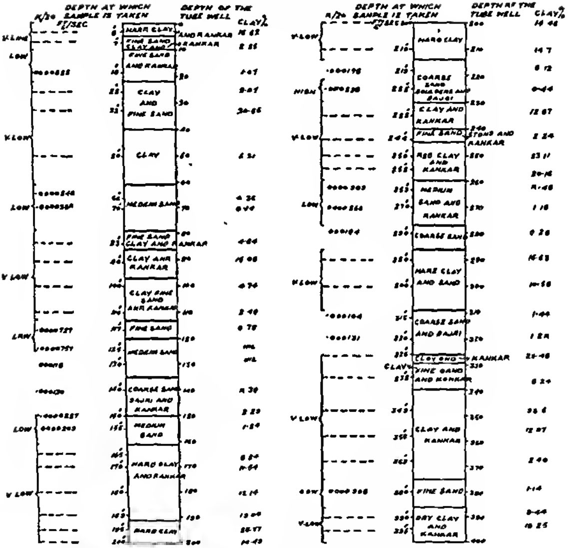


FIG.17

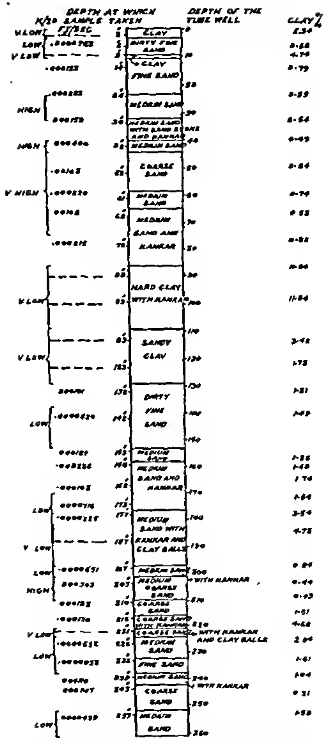
KARNAL GROUP WELL No. 1



ALL PARTICLES ABOVE 2 m.m. DIAMETER REMOVED

FIG.18

KAROL PROJECT WELL No 14



ALL PARTICLES ABOVE 2 mm DIAMETER REMOVED

FIG.19

OPTICAL ARRANGEMENT FOR EXPERIMENTS ON CAVITIES UNDER WEIRS

S = SOURCE OF LIGHT

L_1, L_2 AND L_3 = LENSES

M = MIRROR OF THE VIBROMETER

C = REVOLVING CAMERA

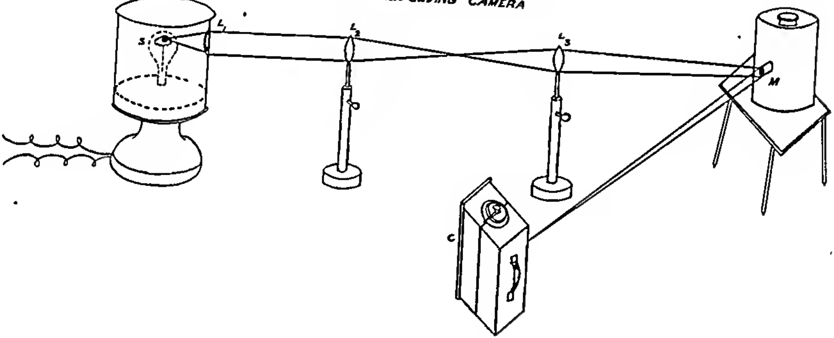
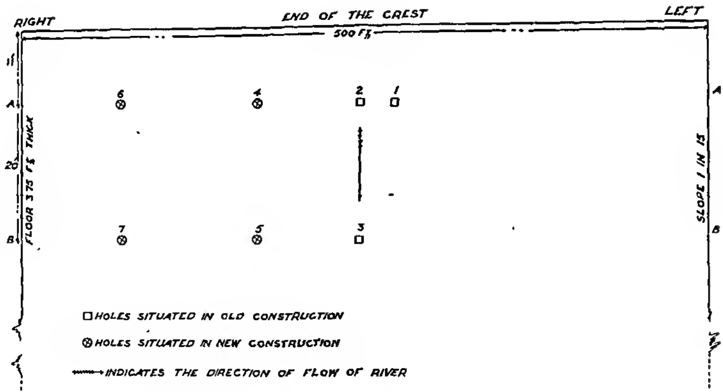


FIG. 20

PLAN OF DOWNSTREAM FLOOR OF BAY No. 3 OF RASUL WEIR



□ HOLES SITUATED IN OLD CONSTRUCTION

⊗ HOLES SITUATED IN NEW CONSTRUCTION

→ INDICATES THE DIRECTION OF FLOW OF RIVER

Fig 21.

VIBROMETER PHOTOGRAPHS TAKEN AT RASUL.

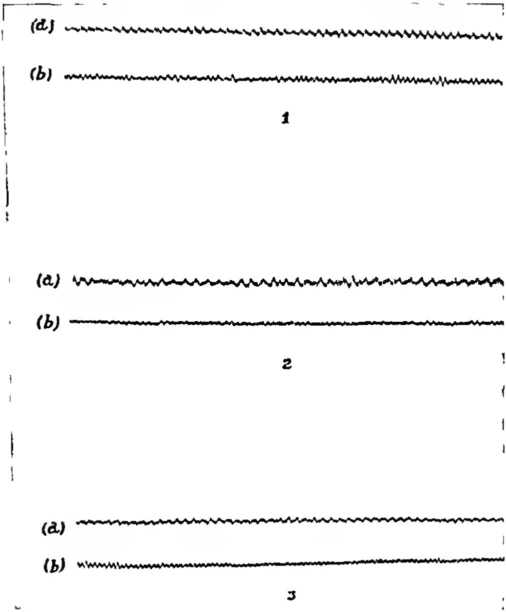


Fig. 22.

VIBROMETER PHOTOGRAPHS TAKEN AT RASUL.

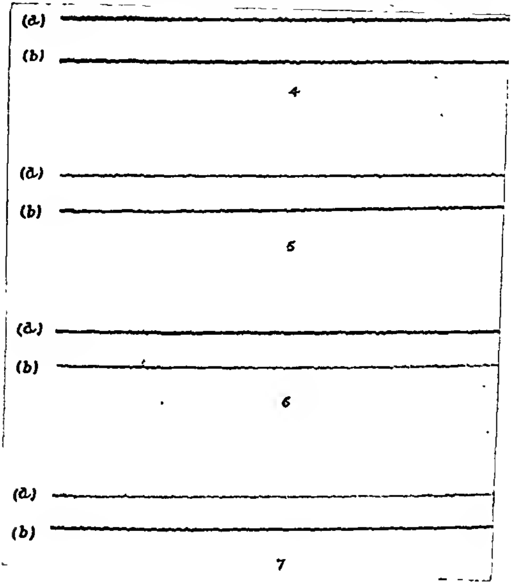


Fig. 23.

PHOTOMICROGRAPHS OF SAMPLES USED FOR NEGATIVE PRESSURES LINEAR MAGNIFICATION 1 : 4.

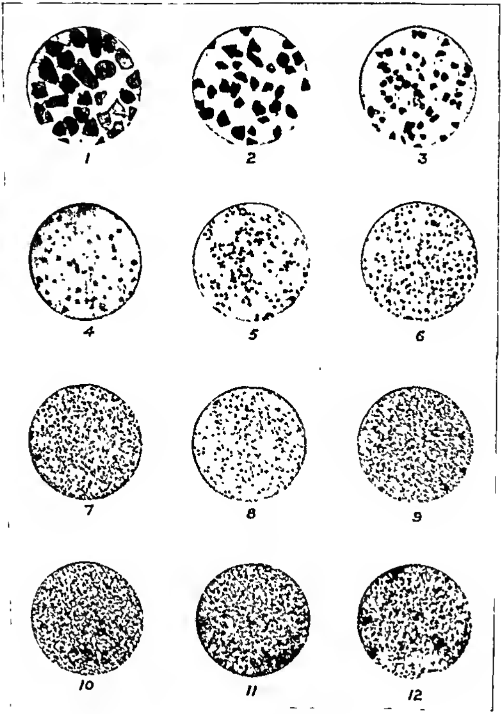


Fig. 24.

EXPERIMENTS ON CAPILLARITY AND WATER-TABLE.

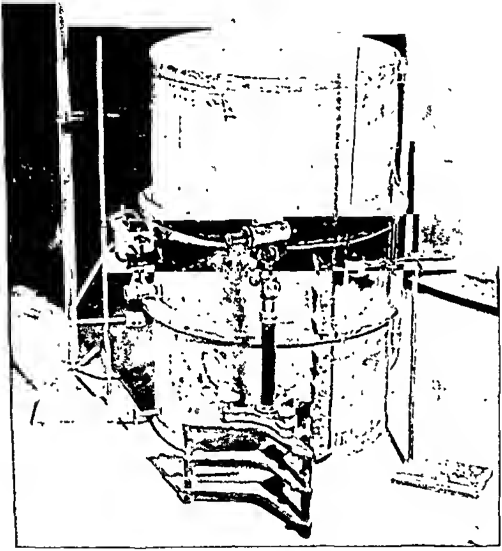


Fig. 24.

EXPERIMENTS ON CAPILLARITY [illegible]

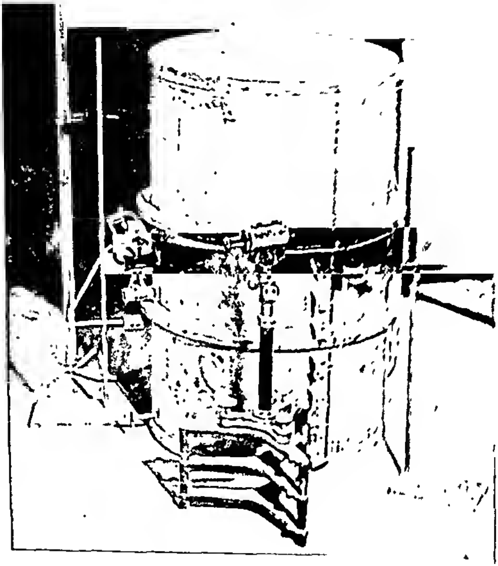


FIG. 26

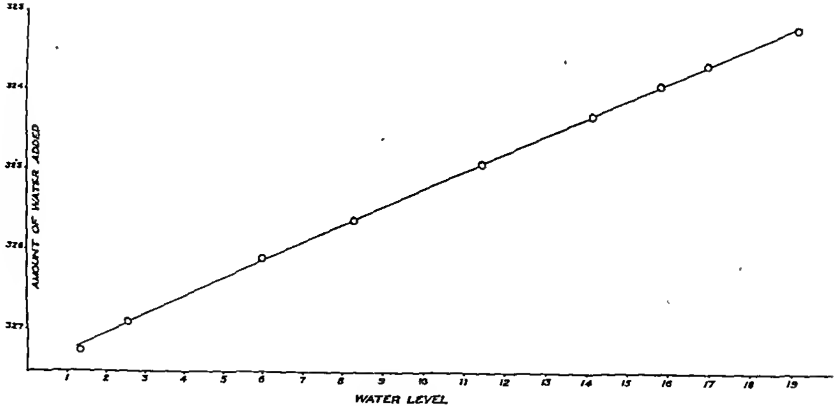

AMOUNT OF WATER ADDED
324
326
327
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
WATER LEVEL

FIG. 27

INDEX PLAN

SHOWING POSITIONS OF PITS DUG ON LINK DRAIN

SCALE 0·5" = 1 MILE

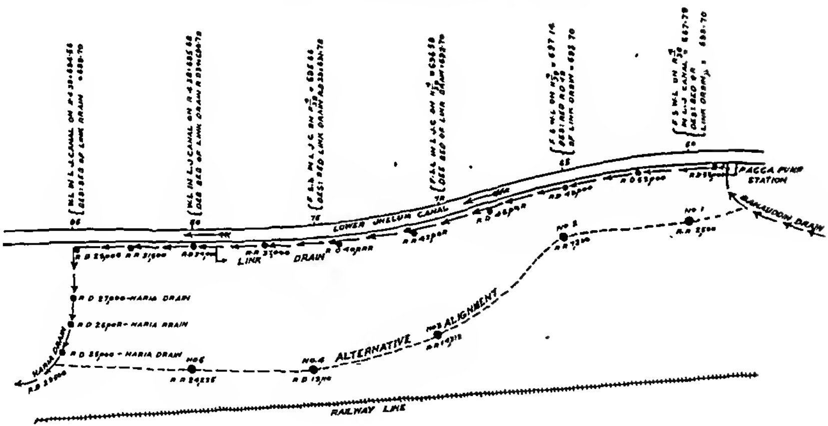
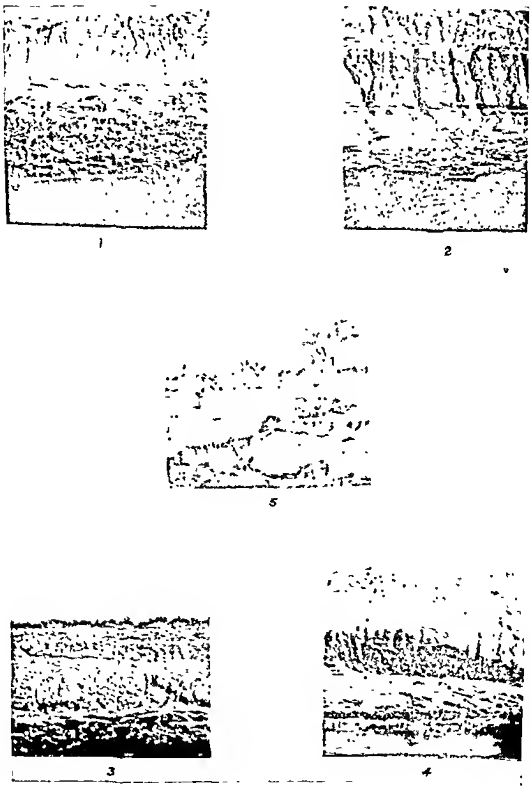


Fig. 28.

STAGES OF PROGRESSIVE FAILURE OF SIDE SLOPES OF DRAINS.



MATHEMATICAL SECTION.

Investigations on the River Chenab at Khanki by means of Models.—Khanki weir was reconstructed in 1934-35 and modifications in the design were introduced with the object of obtaining better control of the river and silt entry into the canal. Regulation rules were drawn up but these were not adhered to rigidly. Various opinions were held regarding the methods to be adopted to achieve the desired results and it was finally decided to test the various suggestions on models of the river and weir. The main problem was to reach a decision regarding the training works necessary and the method of regulation to secure the following results :—

(a) Uniform flow over the weir in high floods.

(b) The discharge in the left arm of the river should be sufficient to feed the canal when the supply in the river was low.

(c) Minimum silt entry into the canal at all stages of the river.

These problems were such that they could not be dealt with in one model unless the size of the model was made so large that the velocities in the pocket were high enough to keep all silt coarser than 0·07 mm. in diameter in suspension. At the same time the model had to be long enough to include a stretch of the river upstream of the head-works so that the inlet conditions of the river were well defined and well-known. Accordingly it was decided to build two models one for studying conditions (a) and (b) and another for condition (c) enumerated above. The first model was built so as to include a stretch of the river between the Khanki Headworks and the railway bridge at Wazirabad where the river flows through a well defined channel and where gauges and discharges are known accurately for a number of years.

At Khanki there are a number of spurs upstream of the head-works each provided with gauges that are read frequently. Down-stream of the railway bridge a cross-section of the river bed is known but nothing is known as to how the river approaches the bridge so that it was very difficult to reproduce the gauge readings at the railway bridge correctly and consequently all the spur gauges showed considerable variations from the prototype values for corresponding discharges. The flow through the bridge was manipulated by adjusting gates at the entrance of the model so as to obtain the observed gauges at the railway bridge and as a result it was found that the spur gauges were correctly reproduced.

Since the conditions of the problem demanded that the whole stretch of the river between the Alexander Bridge and the headworks should be modelled, the dimensions of the available space at the

Experimental Station at Malikpur fixed the horizontal scale. It was found that a horizontal scale ratio of 1/200 could be used so that—

$$l = \text{horizontal scalo ratio} = 1/200$$

The vertical scale ratio was calculated from the following relations—

$$S \times 10^3 = 2{\cdot}09 \frac{m^{\cdot 86}}{Q^{\cdot 21}}$$

and

$$R \propto Q^{1/3}$$

from which is ohtained—

$$d = \text{vertical scale ratio}$$
$$= l^{\cdot 63}\, m^{1/2}$$

For the same silt in the model as in the prototype, the following vertical scale ratio was ohtained—

$$d = 1/30$$

This decided the two length scales. The discharge scale was worked ont from these two scales as follows :—

$$q = 1/33{,}000$$

The next scale ratio that had to be found was the time scale which determines the duration for which a certain discharge in the modol was to he run to reproduce the same hed conditions as are ohtained in the prototype for corresponding discharges. For determining the time ecale, the model was run for the three following scales :—

$1\frac{1}{2}$ hours on the model $\equiv$ 1 month in the prototype.
3 hours on the model $\equiv$ 1 month in the prototype.
$4\frac{1}{2}$ hours on the model $\equiv$ 1 month in the prototypo.

... correct time scale, records of conditions a... fero a cut in the upstream hela was develo... The rate of development of this cut in the model compared very satisfactorily with that in the prototype of which accurate observations were available. This happened for the time scale $4\frac{1}{2}$ hours on the model $\equiv$ 1 month in the prototype. (See Table 10).

The final determination to be made was the quantity of silt that had to bo injected in the model so that the silt equilibrium conditions were obtained. It ... injected in the course of a ... of this quantity of silt wa ... further investigations on this model were carried out by the Hydraulic Section and an account of these is given later in this Report.

The effect of Drains on the Seepage from Canals.—In certain areas it has been necessary to construct a drainage system near a large canal. Recommendations have been made regarding the distance from the canal at which the drain should be constructed so that increased seepage should not take place. In order to obtain more definite information upon which work of this nature could be based in the future, an investigation of the effect of a drain constructed parallel to and at a distance of 1,200 feet from the Upper Gugera Branch, Lower Chenab Canal, was undertaken. The discharge of the Upper Gugera Branch in the reach under investigation is approximately 4,900 cusecs.

Three sites on the drain were selected for observation at R. D's. 70,000, 67,500 and 65,000. At R. D. 70,000 the bed level of the drain is R. L. 682·22 and the width about 15 feet. The corresponding canal bed level is R. L. 681·17 and the Full Supply level is R. L. 692·06. Pipes in which the water level could be observed were installed at the three selected sites on lines running at right angles to the drain and to the canal. In each line twenty-five pipes were placed, seven pipes on the right bank of the canal, the furthest being 1,000 feet from the canal, twelve pipes between the canal and the drain, and six pipes on the left bank of the drain. The lay-out is shown in Fig. 29, the line of pipes "A" being at R. D. 70,000, "B" at 67,500 and "C" at 65,000.

After the pipes had been installed, a canal closure of 24 days duration took place. During the closure the water-table fell and observations given in Table 11 show that there was a slope in the water-table from the drain to the canal. The total drop along the pipes in line "A" was 0·50′, along the line "B" 0·75′ and long the line "C" 0·90′. In line "A" the slope in the water-table can be divided into a fall across the drain of 0·1′ and across the canal of 0·3′. The fall in spring level across the drain and across the canal is due to the flow of water into them during the canal closure. It follows that, if the drain and the canal had not been constructed the water-table would have had a slope of 0·1′ along this line of pipes, that is, a slope of 0·1′ in 2,400 feet.

Variable supplies were run in the canal until 13th March, 1939, when, as is shown in Table 12, it became steady. Observations were made on 18th March, 1939, and the rises in spring level compared with the resting levels of 8th January, 1939, which are given in Table 13. In this table the spring level on the right bank of the canal has been corrected for the presence of the canal. The table shows that the rise in water-level has been slightly greater on the upstream side of the spring level than on the downstream side. The explanation of this result is as follows :—

If the resting spring level had been horizontal in the transverse plane and the drain had not existed then the rises on both sides of the

canal would have been identical. If under this condition of a horizontal water-table, the drain had now been snperimposed the rises in water-table hetween the drain and the canal would hove heen less than those on the right hank of the canal. If the drain had not existed and the water-tahle had a slope in the resting condition, then the rise in water-tahlo on the upstream side of the slope would have heen greoter than that on the downstream side. In the case of the Upper Gugera Branch, o drain had heen constructed on a sloping water-tahle and the combined effect of the canal and the drain had been a greater rise in the water-table on the npstream side than on the downstream side. This shows thot the effect of the drain is smoll compared with the effect of the sloping water-tohle.

The next step in the investigation was to eliminate the effect of the drain. This was done by constructing earthen walls in the drain so os to divide it into comportments and allow the water to head up. Three compartments were made such thot the lines of observations pipes, A, B and C, crossed the centre of their respectivo compartments. The woter-levels in the drain ond pipes rose until they hecame steady on 31st March, 1939. Tohle 14 ond Fig. 30 givo tho results of the observations made. It will he seen that the conal supply level rose hy 0·42′ during the period 19th Morch, 1939—31st March, 1939. Pipe No. 15 which is situoted hetween the eanol and the drain ond at a distance of 100 feet from the drain shows a rise of 0·46′ during the some period. This shows thot the expected increased rise on the npstream side of the spring level takes place. As tho greatest rise tokes ploce on the upstrcom side of the spring level, whether the droin is working or not, it can be concluded that the drain in its present position, 1,200 feet from the conal, is not increasing moterially the seepage from the canal and that this will be a sofe distonce to adopt in future drainage construction.

Silt Observations at Rasul Headworks.—A series of observations wos conducted in 1938 in order thot on attempt could bo made to onalyse the factors determining the quantity of silt entering tho Lower Jhelum Canal. The following observations were taken during the months of June, July, August and September:—

(1) Discharge in the river.

(2) Total silt in suspension in tho river.

(3) Slope of tho river abovo pocket.

(4) Silt entering tho pocket ot six verticals olong a line at the mouth of tho pocket.

(5) Depth of silt in tho pocket.

(6) Silt entering tbe conal in suspension along o line 20 feet awoy from tho regulator gotes ot the middle points of the 8 hoys.

(7) Total silt in suspension at R. D. 5,000 and R. D. 10,000 of the canal.

(8) The amount of silt deposited at R. D. 10,000 of the canal.

(9) Pond level.

The working of the shutters in the weir bays and R. L.'s of the canal regulator gates were also noted.

Fig. 31 gives a plane-table survey of the River Jhelum at Rasul during the winter of 1938. From this it will be seen that the river divides into two channels at the cross line 11-12, the canal taking its supply from the left channel. The discharge in the river in the left arm was observed and the total silt in suspension was determined by means of a bottle sampler at ·6 depth at the centre of the stream in line with gauge 1. By trial observations it was found that the silt at ·6 depth at this point gave the average value of the silt content in a vertical at any point of the river. The quantity of suspended silt has been expressed as grams per litre of river water.

Two gauges marked 1 and 2 existed, gauge 2 being in the pocket and gauge 1 in the river at a distance of 2,125 feet upstream of gauge 2. Four new gauges were established in the river. These were S_1 situated at a distance of 4,038 feet upstream of gauge 1 and on line 11-12, S_2 5,000 feet upstream of S_1 and situated on line 9-10, S_3 5,000 feet upstream of S_2 and situated on line 7-8, and S_4 5,000 feet upstream of S and situated on line 5-6. The river slope was worked out from gauges S_2 and 1. The slope between gauges 1 and 2 was very sensitive to fluctuations in pond level and, therefore, the slope determined from these ganges was unreliable.

Samples of silt in suspensions were taken with a bottle sampler at ·6 D on six verticals situated on a line across the entrance to the pocket. The six samples were mixed together and the total suspended silt determined.

The depth of silt on the floor of the pocket was measured. For the present analysis the average depth of silt on a 40 feet length of the floor immediately in front of the canal regulator has been utilised.

Samples of silt entering the canal were obtained by placing the bottle sampler in the pocket at ·6 depth along verticals 20 feet away from the centre of each of the regulator bays. These samples were mixed, the silt determined and the quantity of silt expressed as grams per litre.

The variables to be considered in this analysis have been divided into two groups (1) Independent Variables: and (2) Dependent

Variables. Dependent Variables are those which are controlled by the variations in the Independent Variables. For example, the river slope is controlled by variations in the pond level. The variables are :—

Independent Variables.

(1) Discharges in the left arm of the river.
(2) Silt in the river.
(3) Temperature of river water.
(4) Canal discharge.
(5) Pond level.
(6) Regulation of weir shutters.

Dependent Variables.

(1) Silt entering the pocket.
(2) Silt entering the canal.
(3) River slope.
(4) Depth of silt in the pocket.

The two variables, silt in the river and silt entering the canal are inter-connected. In order to study the effect of the one on the other, the ratio between these variables has been examined and expressed as a new variable " α ".

$$\text{where } \alpha = \frac{\text{Silt in the left arm of the river}}{\text{Silt entering the canal}}.$$

A ratio " β " has also been worked out for the discharges in the river and in the canal.

$$\beta = \frac{\text{Discharge in left arm of river}}{\text{Discharge in canal}}.$$

Variations in the ratio " β " are mostly due to variations in the river discharge since the canal discharges are generally constant. At times fluctuations in the canal supply do occur and β becomes important under these conditions in a steady river.

The variables have now been reduced to α, β, the depth of silt in the pocket and the slope of the river. During the four months, June—September, attempts were made to keep the regulation as steady as possible. In the analysis the variables have been tabulated over periods of steady regulation and are given in Table 15. From this table it will be at once apparent that the two factors, river slope and depth of silt in the pocket, are the most important factors that influence

the entry of silt into the canal. An increase of discharge in the river brings in an increased load of silt in the water and a corresponding increase of silt into the canal. This fact is well-known but the present analysis brings out the following :—

(1) An increase in the river slope brings in more silt into the canal.

(2) An increase in the depth of silt in the pocket results in more silt entering the canal.

During 1939-40 it is proposed to study these conclusions more rigorously and also to determine the effect of regulation when all the other factors are steady.

It will be seen that the above analysis is purely qualitative. An attempt at quantitative analysis was made but with little success. This is due to the fact that the method of sampling silt by the bottle sampler is qualitative. Until quantitative measurements can be obtained it will not be possible to draw any quantitative conclusions. Efforts are being made to devise an apparatus in order to make quantitative measurements of silt in suspension.

Observations of Regime Sites.—It has been shown previously that the following relations have been found to hold good for the sites selected for regime conditions in the Punjab :—

$$S \times 10^3 = 2\cdot09 \frac{m^{\cdot 86}}{Q^{\cdot 21}} \quad .. \quad .. \quad .. \quad (1)$$

$$P = 2\cdot82\ Q^{1/2} \quad .. \quad .. \quad .. \quad (2)$$

$$R = \cdot47\ Q^{1/3} \quad .. \quad .. \quad .. \quad (3)$$

where P, Q, R, S are respectively the wetted perimeter, the discharge, the hydraulic mean radius, slope of the channel and ' m ' the mean diameter in mm. of the bed silt in the canal under consideration. It had been noticed that the relations (2) and (3) hold for regime as well as for non-regime channels. It was decided to investigate these relationships more thoroughly. With this object in view, new sites have been selected and will be kept under observation.

Relation (1) has been deduced from channels that flow in incoherent alluvium and in which the perimeter has been artificially prepared. It is proposed to investigate this relationship for boulder and alluvial rivers in addition. For this purpose a site on the River Ravi at Mukoswar where the river just emerges from the hills and where its bed consists of boulders and pebbles has been selected. It is proposed to take discharges, slope and bed samples at this place over a range of discharges from 10,000 cu-ft./sc. to 20,000 cu.ft./sc. the lower limit being due to the fact that for lower discharges velocities are so low

that no bed load movement is expected to take place and the upper limit is fixed by the fact that at this stage the velocities will be so high that it will not bo possible to take them from a boat. The site has now been equipped for the observations.

The examination of the river Mississippi Data according to Regime Formulæ derived in India.—During the period January 12, 1937, to May 16, 1938, a series of hydraulic observations was carried out by the staff of U. S. Waterways Experiment Station, Vicksburg, at sites marked in the plan of the Mississippi river (Fig. 31*a*) as Ranges I, II and III. These observations have now been published as Technical Memorandum No. 122-1 "Study of Materials in suspension, Mississippi River" by the U. S. Waterways Experiment Station. These data afford an exce[illegible] to what extent the regime formulæ [illegible] Institute can be applied to river sy[illegible] formulæ derived by Mr. Lacey have also been examined in a similar manner.

The following procedure was followed in making a complete field observation. This is reproduced from the above publication.

Details.—" To accomplish the purpose of the study it was necessary to obtain samples of river water, velocity measurements and other data from various points over the cross-section of the range. It was essential that all measurements involved in a given observation be made as nearly simultaneously as practicable. To that end, the procedure described in the sub-paragraphs below was developed and in general was follows :—

" (*a*) *First step—development of section.*—The first step in the procedure was the development of the river cross-section by sounding operation."

" (*b*) *Second step—setting of rangeposition.*—The data obtained in step *a* above was plotted as they were collected by the observer. On the resulting cross-section range positions were marked off. The cross-section and range position lines of Fig. 31 *c* are typical of the appearance of the plot at this stage. Normally the range position was spaced at intervals of from 400 to 600 feet. Special range positions were placed at points where irregularities in bed and banks existed."

" (*c*) *Third step—obtaining of samples.*—The boat was brought and held for the first range position. By use of the horizontal sampling device, samples of river water then were obtained at distances from the bottom, respectively, as follows :—"

" 0 inch, 3 inches, 6 inches, 1 foot, 2 feet, 4 feet. By use of the vertical sampling device, samples of river water then were obtained at depths 0·2,

0·4, 0·6, and 0·8 of the sounded depth of the range positions in question. Samples of surface water then were scooped out. Water temperature was observed at various times. These observations were repeated at alternate range positions across the section, following which the same procedure was applied to the remaining range position. Bed samples were obtained on completion of the foregoing operation."

" (d) *Fourth step—obtaining of velocity measurements.*—Following completion of step *c* above, the boat was manouvered to each of the range position in turn, and velocity measurements were taken at practically all points at which samples had been taken. Thus in each range position velocity measurements were obtained at increments of 0·2 of the depth from the surface to the bottom and at distances of 2 feet and 4 feet from the bottom".

During the experiments, a total of ten field observations were made. Each observation involved the taking of from 46 to 114 samples and obtaining the corresponding velocity measurements. These observations have been designated by number from 1 to 10. All observations except No. 6 were made at Range No. 2; observation No. 6 was made at Range No. 3. Fig 31 *b* shows the hydrograph of the river Mississippi during the period at Vicksburg. The dates on which the observations were made are indicated in the hydrograph. In this connection it may be noted that Mayersvilla where these observations were taken is 70 miles above Vicksburg. Reference to Fig. 31 *a* and Fig. 31 *c* indicates the general features of the Mayersvilla range. It is located in a flat bend of the river (radius of curvature about 14,000 yards). The ratio of mean depth to width at mean low water is about 1 to 270. The left river bank is composed of firm, silty material; the right bank is composed of sandy deposits and the river bed is composed of loose sand of varying size composition.

In submitting this report the Director of the Experiment Station, Vicksburg, concludes with the following remarks :—

This report is essentially a compilation of basic data; it presents no new formula and no far reaching conclusions.

These data have been analysed in the Punjab Irrigation Research Institute

Regime.—Before this analysis could be started it was necessary to be satisfied that these data referred to regime sites. Figs. 31 *c*—*f* show the cross-section of the river at this site for different stages. During the observations 7 to 10 over a period February 1st to May 16th

of 1938 the general contour of this river bed remained practically unaltered as is apparent from these figures. For obseivations Nos. 2 and 3 where the river discharge was over one million cusecs the river overflowed the banks and the data are not reliable. These have. therefore, been rejected. During Observation No. 6 the supply was low and the site was changed to Range III. Hence this observation has also been rejected. Summation curves for the bed silt samples have been supplied only for the observations 7 to 10. From these the average diameters have been worked out. Table 16 gives the results of this analysis.

As has been pointed out earlier this stretch of the river Mississippi had been steady for over a period of sixteen months. All the crosse-sections of the river taken during this period show that this was the case. Those cross-sections taken during floods higher than one million cusecs when the river overflowed its banks and during very low discharge when only a creek was flowing related to non-regime river conditions. These observations have not been taken into consideration in the above calculation.

This analysis shows that the following relationship derived from the Punjab canal data—

$$S \times 10^3 = 2{\cdot}09 \frac{m^{\cdot 86}}{Q^{\cdot 21}}$$

holds good also for rivers such as Mississippi even for such high stages as given by discharges over nine lakhs cubic feet per second. The calculated slopes agree remarkably well with the observed slopes in the falling stages of the river, while during the rising stage the agreement is slightly worse. This may be due to the fact that during the rising [illegible] will be [illegible] all so [illegible] ..me lag in guage reading as a flood is passing, fluctuation in the gauage readings which when the river is rising are much more than when it is falling.

In the table 16 some of the formula derived by Mr. Lacey have also been compared. The results may be briefly indicated here:—

(1) The regime relation $V = 16 \sqrt[3]{R^2S}$ is not satisfied though *the sections Fig. 31c-f* and the Irrigation Research Institute formula $S \times 10^3 = 2{\cdot}09 \dfrac{m^{\cdot 86}}{Q^{\cdot 21}}$ show that the site is in regime.

(2) $\frac{P}{\sqrt{Q}}$ relationship which was found to hold good for Punjab canal data with slightly different constants (2·2 to 3·2), gives very high values for the Mississippi river.

(3) $Q^{1/3}/R=2\cdot13$, a Lacey formula modified to suit Punjab condition gives slightly higher values from this set of data.

(4) The two values of f calculated from—

$$V = 1\cdot15\sqrt{fR} \text{ and}$$

$$S = \cdot00039\frac{f^{5/3}}{q^{1/3}}$$

differ by more than 100 per cent. in some cases.

The Secretary, Central Board of Irrigation, is to be asked to arrange to collect similar reliable data for rivers from India and outside.

Experiments on Silt Movement in a Tilting Flume.—In this flume the bed slope can be varied by tilting the whole flume. The experiments already undertaken form part of a series to be carried out to find the value of the tractive force exerted by a sandy bed on the movement of water over such a bed for various discharges, depths of water and slope of water surface.

To determine the frictional force offered by pipes of different rugosity Professor Prandtl extended the experiments of Nikuradse on pipe flow. The pipe used in these experiments was of a square section, three sides being perfectly smooth and the fourth side moveable. The rugosity of this fourth side was varied and the velocity distribution in different cross-sections of the pipe obtained. From this velocity distribution he deduced the frictional resistances of plates of different rugosity.

It is proposed to modify this technique to suit the open surface flow in flumes. The sides and the bed of the flume have been lined with glass plates so that they may offer friction which will be constant under all conditions except for temperature fluctuation and will also be a minimum for all rigid boundaries. If the assumption that the air at the free surface may be taken as a boundary is valid, then Prandtl's results in a square pipe may be extended to the present case of flow in flumes and the following relation can be expected to hold:-

$$\frac{u}{v_*} = 5\cdot5 + 5\cdot75 \log \frac{v_* y}{\nu}$$

where

$$v_* = \sqrt{\frac{\tau}{\rho}}$$

and u is the velocity at a distance y from the smooth wall, τ the frictional force offerred by the wall and ρ the density of water, ν its kinematic visocosity. If, therefore, volocities are observed at different heights from the bed of the flume along different verticles and n plotted against log y we should expect a straight line relation of the form—

$$n = m + n \log y.$$

Velocities have been observed by means of Pitot Tubes in different sections of the flume. In Figs. 32—40, these velocities have been plotted against log y for those sections of the flume where the flow had become steady. These figures show that u and log y follow the above straight line relation of Prandtl. From this it is clear that flow in a flume follows the same laws as the flow in a pipe.

If now it be assumed that τ_b and τ_s be the frictional forces of the bed and the free surface and d_1, d_2, $(d=d_1+d_2)$ be the distances of the point of maximum velocity from the bed and from the free surface then it can be proved that—

$$\tau_b/\tau_s = d_1/d_2$$

This follows from the fact that in a fully developed turbulent region the frictional force at any point in the liquid medium can be expressed as a linear function of the distance from the boundary, so that at any point in the liquid the frictional force τ_p is given by—

$$\tau_p = \tau_b + k \cdot y$$

At the point where the *maximum* velocity occurs it is well-known that $\tau_p = o$ so that at this point of maximum velocity —

$$\tau_b = -k\,d_1$$

Similarly if we start from the free surfaco, we get at tho point of maximum velocity—

$$\tau_s = -k\,d_2$$

$$\therefore\ k = -\frac{\tau_b}{d_1} = -\frac{\tau_s}{d_2}$$

$$\text{or}\qquad \frac{\tau_b}{\tau_s} = \frac{d_1}{d_2}$$

Now from the velocity distribution curves it is possiblo to know the ratio d_1/d_2, see Figs. 32—40. It will be seen that so long as the boundary surfaces retain tho samo rugosity the value of this ratio remains constant. Assuming the value of the air surface friction τ_s as constant

from these experiments it will be possible to find the value of the bed surface friction τ_b from the following relation—

$$\tau_b = \left(\frac{d_1}{d_2}\right) \tau_s = \lambda \ \tau_s$$

where—

$$\lambda = d_1/d_2$$

If now this bed be made of different grades of sand and from velocity observations we find the corresponding value of λ, then—

$$\tau_{b_1} = \lambda_1 \ \tau_s \text{ , } \tau_{b_2} = \lambda_2 \ \tau_s$$

where τb_1 λ_1 refer to one class of sand and τ_{b_2}, λ_2 to a different grade of sand. It will then be possible to find the ratio of their rugosity from—

$$\frac{\tau_{b_1}}{\tau_{b_2}} = \frac{\lambda_1}{\lambda_2}$$

TABLE 10.

D/S distance in ft.	Width of the cut in the model.	Width of the cut in the prototype.
Feet.	Feet.	Feet.
0	7·75	4·03
1	6·67	6·7
2	5·83	6·0
3	5·75	5·0
4	5·33	4·0
5	4·67	4·0
6	4·0	3·0
7	2·5	2·[illegible]
8	2·17	2·0
9	2·67	2·0
10	2·67	2·0
11	2·67	2·0
12	2·67	2·0
13	2·67	2·0

The cut to begin with was made about 50 per cent. wider.

TABLE 11.

DATED 8th January, 1939.

No.	Depth of S. L. below top of pipes *plus* Sounder's length.	A line R. L. of Subsoil Water.	Depth of S. L. below top of pipes *plus* Sounder's length.	B line R. L. of Subsoil Water.	Depth of S. L. below top of pipes *plus* Sounder's length.	C line R. L. of Subsoil Water.
1	6·44	683·73	6·37	683·01	7·07	682 31
2	7·11	683·72	7 91	683·11	7·40	682·36
3	8·62	683·72	9·32	683·10	5·40	682·39
4	7·99	683·67	7·12	683·14	6·01	682·40
5	9·56	683·67	7·91	683·17	8·44	682·43
6	11·08	683·69	13·11	681·95	12·54	682·34
7	12·01	683·66	10·02	683·20	11·09	682·67
C. G.	0·09	683·37	0·08	682·89	0·11	682·2[illegible]
8	12 20	683·71	11·67	683·44	11·58	682·7[illegible]
9	11·91	683·73	13 51	683 48	12·60	682·4[illegible]
10	8·69	683 74	8·70	683 35	7·93	682·5[illegible]
11	8·77	683·78	7 63	683 47	8 35	682·5[illegible]
12	8·63	683 87	6 98	683 40	6 06	682·6[illegible]
13	8·05	683·98	*	*	7 03	682·7[illegible]
14	7·45	684·19	7·36	683·50	7·64	682·0[illegible]
15	7 03	684·61	6·21	683·38	6·88	682·9[illegible]
16	7·01	684·48	6·71	683·57	6·80	683·0[illegible]
17	6·98	684·25	6·56	683·56	6·37	683·0[illegible]
18	6·19	684·39	7·79	682·54	7·59	683·0[illegible]
19	5·61	684·07	6·09	683·50	6·40	682·9[illegible]
D. G.	6·28	683·78	0·79	683·00	0·12	682·3[illegible]
20	4·94	684 08	6·32	683·54	5·48	683·0[illegible]
21	6·87	684·11	7·36	683·58	7·09	683 0[illegible]
22	7·50	684·24	5·76	683·64	6·90	683·0[illegible]
23	7·86	684·20	6·79	683·63	7·80	683·0[illegible]
24	6·48	684·18	5·75	683·70	7·45	683·11
25	6·	684·23	5·17	683·78	8·14	683·21

*Pipe is filled with earth.

TABLE 12.

DATED 18th March, 1936.

No.	Depth of S. L. below top of pipes *plus* Sounder's length.	A line R. L. of Subsoil Water.	Depth of S. L. below top of pipes *plus* Sounder's length.	B line R. L. of Subsoil Water.	Depth of S. L. below top of pipes *plus* Sounder's length.	C line R. L. of Subsoil Water.
1	4·68	685·49	3·99	684·39	6·63	683·35
2	4·35	686·48	5·61	685·11	5·66	683·69
3	5·56	686·84	7·05	685·37	3·96	683·83
4	4·59	687·07	4·73	685·53	4·51	683·90
5	5·97	687·26	5·43	685·65	6·83	684·04
6	7·46	687·37	10·52	685·76	16·77	684·11
7	8·04	687·63	8·09	686·03	9·25	684·51
C. G.	3·20	692·10	2·81	691·72	2·88	691·28
8	8·23	687·68	9·01	686·10	9·19	683·11
9	8·11	687·53	11·21	685·76	10·89	684·22
10	5·09	687·34	*	*	6·35	684·15
11	5·39	687·16	5·36	685·74	4·79	684·11
12	5·82	686·68	4·93	685·45	4·68	684·03
13	5·63	686·35	6·04	685·34	5·82	684·62
14	6·77	685·87	5·00	684·85	6·63	684·01
15	5·11	685·53	4·94	685·06	5·86	684·00
16	6·01	685·48	5·54	684·74	5·81	684·00
17	6·61	685·41	5·48	684·64	5·41	683·96
18	5·76	685·25	5·79	684·54	6·65	683·95
19	4·45	685·23	5·21	684·38	5·48	683·91
D. G.	2·16	683·95	0·92	683·17	0·47	682·68
20	3·97	685·65	5·46	684·40	4·5[illegible]	683·95
21	5·66	685·32	6·36	684·58	6·14	684·00
22	6·42	685·32	4·67	684·73	5·95	684·01
23	6·61	685·45	5·67	684·75	6·85	684·04
24	5·16	686·50	4·64	684·81	6·49	684·07
25	5·66	685·50	4·05	684·88	7·19	684·16

*The drains are running.

TABLE 13.

Rises in Spring Level as recorded on 18th March, 1939 compared with the Resting Spring Level on 8th January, 1939.

Distance from the water edge of the canal.	Rises on B line		Difference.
	Left.	Right.	
Feet.	Feet.	Feet.	Feet.
200	2 12	2·06	..
300	2·05	1·82	·23
400	1·93	1 81	·12
500	1·81	1·60	·21
600	1·69	1·50	·19
700	1·57	1·37	·20
800	1·47	1·26	21

TABLE 14.

WATER LEVELS IN PIPES ALONG LINE B.

Pipe No.	Distance of pipes from the water edge of canal.	On 18th March, 1939.	On 31st March, 1939.	Rises in Level.
	Feet.			Feet.
1	1,000	684·39	684·49	6·1
2	400	685·1	685·34	0·23
3	200	685·37	685·87	6·30
4	100	685·53	685·81	6·28
5	50	685·65	685·95	0·36
6	15	685·76	686·08	0·32
7	1	686·03	686·37	0·34
Canal Gauge	0 } 0 }	691·72	692·14	6·42
8	1	686·10	686·44	0·34
9	15	685·76	686·06	0·70
10	50	..	686·11	--
11	100	685·74	688·05	0·31
12	310	685·45	685·75	0·30
13	620	685·24	685·59	0·30
14	730	885·06	685·43	6·37
15	940	684·85	685·31	0·48
16	990	684·74	685 29	0·55
17	1,020	684·64	685·27	6·63
18	1,630	684·54	685·26	0·72
19	1,039	683·38	685·27	6·89
Drain Gauge	1,040 } 1,056 }	683·17	685·11	1·94
20	1,656	684·40	685·25	0·85
21	1,665	684·58	685·27	6·69
22	1,076	684·73	685·32	0·59
23	1,105	684·75	685·28	6·53
24	1,155	684·81	685·27	0·46
25	1,255	684·88	685·27	0·39

TABLE 15.

Rasul Headworks Silt Observation, 1933-39.

Period.	Discharge.		River Slope.	Pond silt.	Silt.	
	River.	Canal			River.	Canal
June.						
1—8	Steady	Steady	Steady	Increasing 705·9—8·2	Decreasing	Increasing.
20—22	Decreasing	Increasing	Decreasing	Steady	Increasing	Decreasing.
22—26	Steady	Steady	Steady	Increasing 703·3—704·1	Decreasing	Increasing.
27—30	Decreasing	Increasing	Increasing ·25—·30	Increasing 704·2—705·7	Increasing	Decreasing.
July.						
1—6	Steady	Steady	Decreasing ·32—·28	Steady	Increasing	Decreasing.
6—11	Steady	Steady	Almost steady.	Increasing 706·3—708·7	Decreasing	Increasing.
21—24	Increasing	Decreasing	Increasing ·17—·32	Increasing 706·2—707·8	Decreasing	Increasing.
24—2nd Aug.	Decreasing	Increasing	Decreasing ·32—·14	Decreasing 707·8—706·3	Increasing ·71—2·8	Decreasing.
August.						
3—9	Steady	Steady	Steady	Increasing 706·3—708·0	Decreasing 2·8—1·4	Increasing
17—22	Decreasing	Increasing	Decreasing ·42—·29	Increasing 703·0—705·0	Steady 6·63—6·05	Steady
24—27	Increasing	Decreasing	Increasing ·25—·39	Increasing 705·1—705·5	Decreasing	Increasing.

TABLE 16.

Observation No.	Date.	Q Discharge in cu./sec.	Rising or falling stage.	V in ft./sec.	P Wetted Perimeter in ft.	R Hydraulic Mean radius in ft.	m Bed Silt Diam in mm.	Slope × 10^3 Observed.	Slope × 10^3 Calculated (1).	$\frac{P}{\sqrt{Q}}$ Lacey (2).	$\frac{Q^{1/3}}{R}$ I. R. I. (3).	1 Lacey (4).	f2 Lacey (5).	V / $\sqrt[3]{R^2 S}$ Lacey (6).
1	12th January, 1937.	787,000	R	4·04	4,684	34·17	..	·065	..	5·28	2·70	·951	0·540	11·68
4	16th June, 1937..	521,000	R	3·62	5,200	27·60	..	·051	..	7·21	2·91	·741	·358	10·68
5	19th July, 1937 ..	340,530	F	3·44	5,010	21·45	..	·018	..	7·91	3·20	·673	·417	12·24
7	1st February, 1938	608,000	R	4·28	4,760	29·07	·41	·068	·059	6·09	2·83	·925	·462	10·80
8	24th February, 1938.	925,740	R	4·50	5,406	37·52	·39	·068	·052	5·62	2·60	·981	·410	9·98
9	11th May, 1938 ..	614,000	F	4·01	5,189	29·49	·39	·055	·057	6·62	2·88	·802	·412	11·05
10	16th May, 1938 ..	545,125	F	4·28	4,856	26·45	·39	·058	·058	6·58	3·09	·819	·524	11·80

1. The values were calculated from the Punjab Irrigation Research Institute formula $S \times 10^3 = 2{\cdot}09 \frac{m^{\cdot 86}}{Q^{\cdot 21}}$

2. According to Lacey $P = 2{\cdot}67\sqrt{Q}$.

3. According to Punjab Irrigation Research Institute, $Q^{1/3}/R = 2{\cdot}13$ modification of Lacey — to make it applicable to the Punjab Canals.

4. Worked out from Lacey $S = {\cdot}00039 \frac{f^{5/3}}{q^{1/3}}$

5. Worked out from Lacey $V = 1{\cdot}15\sqrt{fR}$.

6. Worked out from Lacey $V = 16\sqrt[3]{R^2 S}$; 1·8

FIG.29

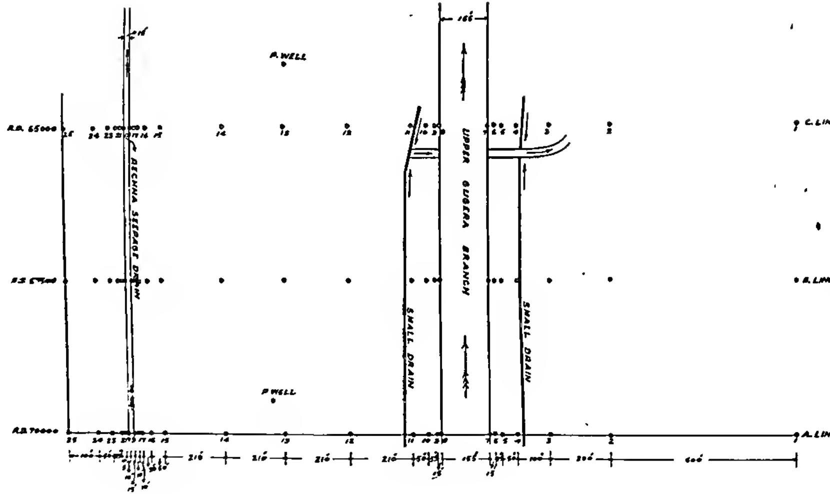
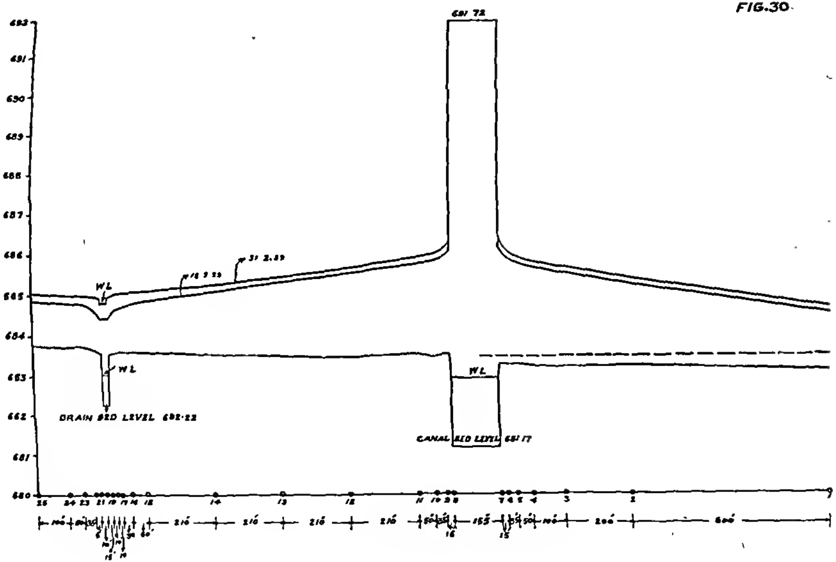

UPPER GUGERA BRANCH
SMALL DRAIN
SMALL DRAIN
RECHNA SEEPAGE DRAIN
A. WELL
P WELL
C. LINE
B. LINE
A. LINE

FIG.30



PART SURVEY PLAN OF JHELUM RIVER
AT RASUL YEAR 1938

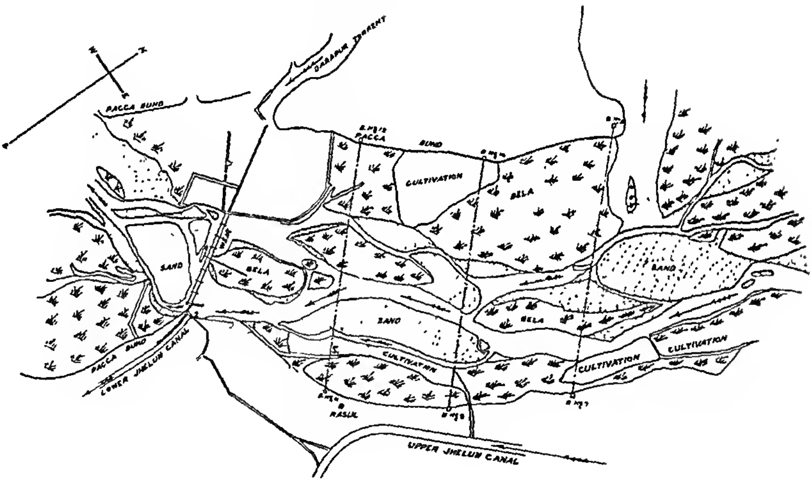
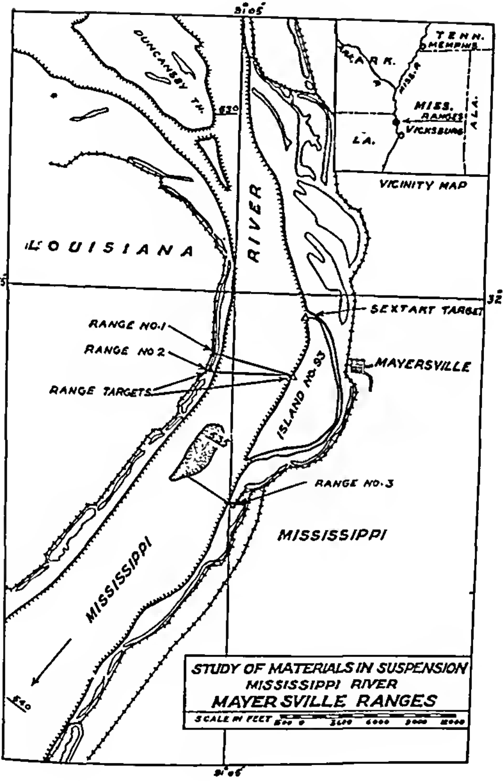
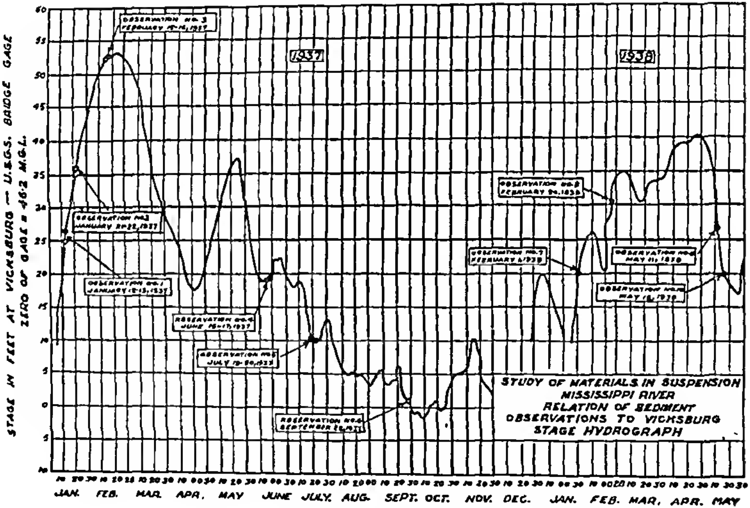


FIG. 31 (a)



91°05'
DUNCANSBY TH.
TENN.
MEMPHIS
ARK.
MISS. R.
MISS.
RANGES
ALA.
VICKSBURG
LA.
VICINITY MAP
LOUISIANA
RIVER
32°55'
32°55
SEXTANT TARGET
RANGE NO. 1
RANGE NO. 2
MAYERSVILLE
RANGE TARGETS
ISLAND NO. 93
RANGE NO. 3
MISSISSIPPI
MISSISSIPPI
STUDY OF MATERIALS IN SUSPENSION
MISSISSIPPI RIVER
MAYERSVILLE RANGES
SCALE IN FEET
91°05'

FIG. 31 (b)



STUDY OF MATERIALS IN SUSPENSION
MISSISSIPPI RIVER
RELATION OF SEDIMENT
OBSERVATIONS TO VICKSBURG
STAGE HYDROGRAPH
1937
1938
STAGE IN FEET AT VICKSBURG — U.S.G.S. BRIDGE GAGE
ZERO OF GAGE = 46.2 M.G.L.
JAN. FEB. MAR. APR. MAY JUNE JULY AUG. SEPT. OCT. NOV. DEC. JAN. FEB. MAR. APR. MAY

FIG. 31 (C)

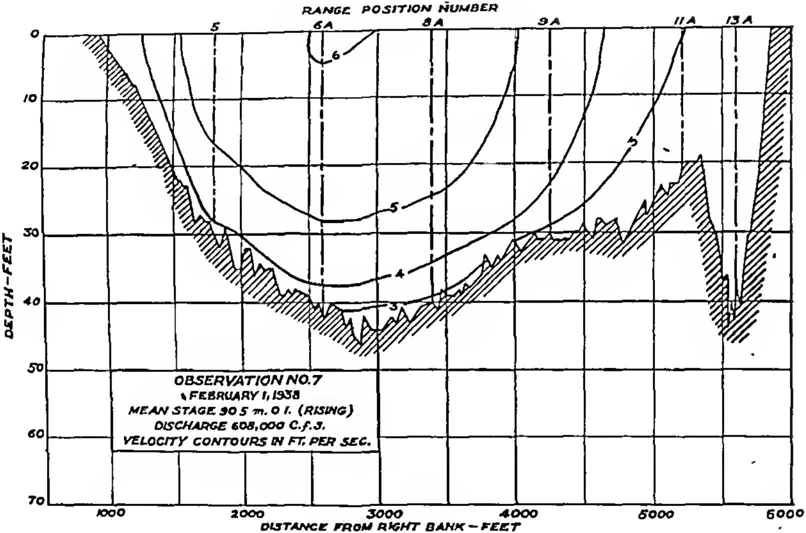

RANGE POSITION NUMBER
5
6A
8A
9A
11A
13A
0
10
20
30
40
50
60
70
DEPTH-FEET
6
5
4
3
OBSERVATION NO.7
FEBRUARY 1, 1938
MEAN STAGE 90.5 m.o.l. (RISING)
DISCHARGE 608,000 C.f.s.
VELOCITY CONTOURS IN FT. PER SEC.
1000
2000
3000
4000
5000
6000
DISTANCE FROM RIGHT BANK - FEET

FIG. 31 (a)

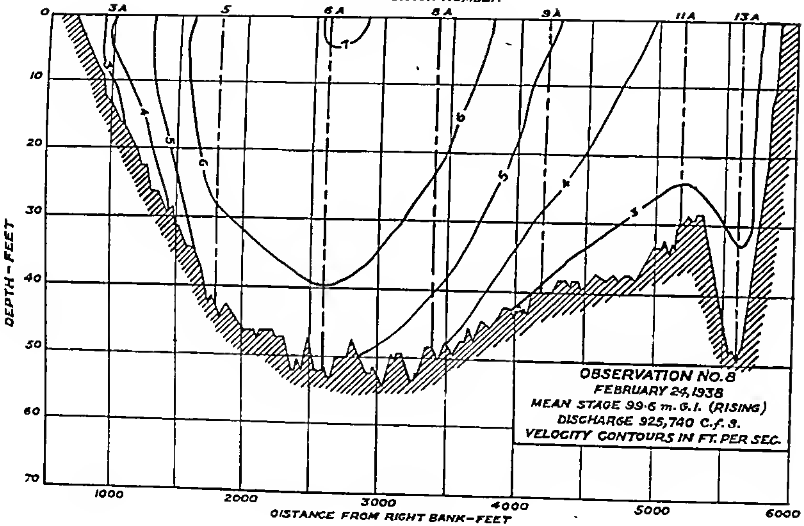

RANGE POSITION NUMBER
3A
5
6A
8A
9A
11A
13A
DEPTH - FEET
0
10
20
30
40
50
60
70
1000
2000
3000
4000
5000
6000
DISTANCE FROM RIGHT BANK-FEET
OBSERVATION NO. 8
FEBRUARY 24, 1938
MEAN STAGE 99·6 m.G.I. (RISING)
DISCHARGE 925,740 C.f.S.
VELOCITY CONTOURS IN FT. PER SEC.

FIG. 31 (e)

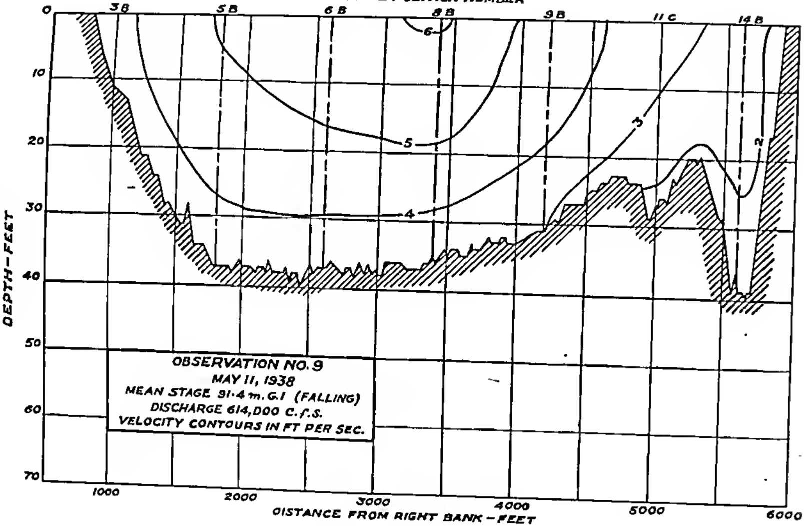
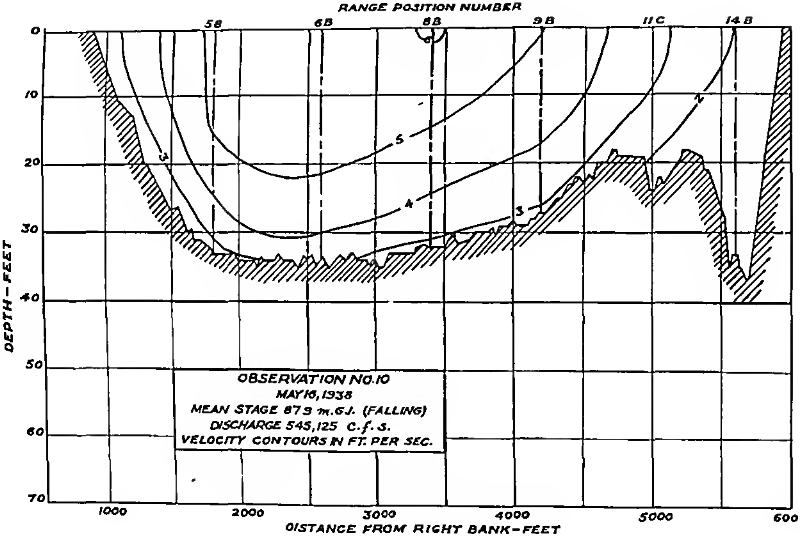

RANGE POSITION NUMBER
3B
5B
6B
8B
9B
11C
14B
0
10
20
30
40
50
60
70
DEPTH-FEET
6
5
4
3
2
1
OBSERVATION NO. 9
MAY 11, 1938
MEAN STAGE 91·4 m. G.I (FALLING)
DISCHARGE 614,000 C.f.S.
VELOCITY CONTOURS IN FT PER SEC.
1000
2000
3000
4000
5000
6000
DISTANCE FROM RIGHT BANK - FEET

FIG. 31 (f)


RANGE POSITION NUMBER
5B
6B
8B
9B
11C
14B
0
10
20
30
40
50
60
70
DEPTH - FEET
1000
2000
3000
4000
5000
6000
DISTANCE FROM RIGHT BANK-FEET
2
3
4
5
6
3
OBSERVATION NO.10
MAY 16, 1938
MEAN STAGE 87.9 m.G.L. (FALLING)
DISCHARGE 545,125 c.f.s.
VELOCITY CONTOURS IN FT. PER SEC.

DISCHARGE 1 CUSECS

VELOCITIES OBSERVED IN A SECTION 4·0 FT U/S OF THE EXIT END ALONG VERTICAL 0·0 FT FROM THE CENTRE OF THE FLUME AND 0·48 FT FROM THE GLASS SIDE. THE BED WAS ALSO GLASS.

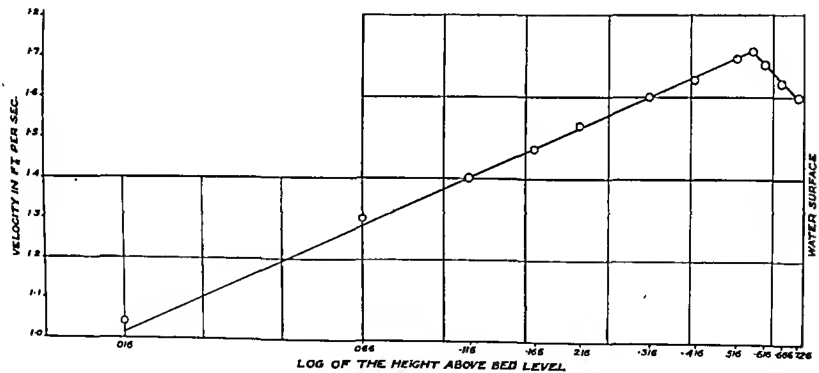


FIG.33

DISCHARGE 1 CUSECS

VELOCITIES OBSERVED IN A SECTION 4·0 FT U/S OF THE EXIT END ALONG VERTICAL ·05 FT FROM THE CENTRE OF THE FLUME AND ·43 FT FROM THE GLASS SIDE. THE BED WAS ALSO GLASS

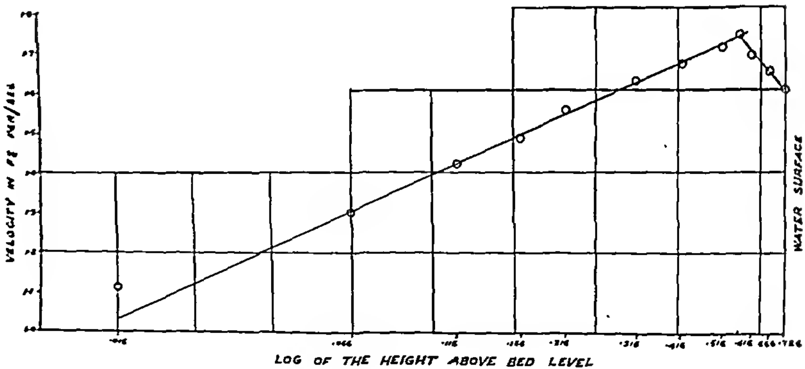


FIG.34

DISCHARGE 1 CUSECS

VELOCITIES OBSERVED IN A SECTION 4·0 FT. U/S OF THE EXIT END ALONG VERTICAL 0·1 FT. FROM THE CENTRE OF THE FLUME AND 0·38 FT. FROM THE GLASS SIDE THE BED WAS ALSO GLASS

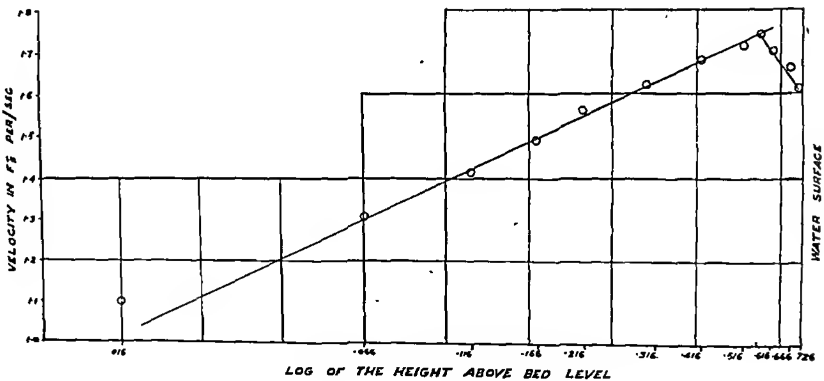


FIG.35

DISCHARGE 1 CUSECS

VELOCITIES OBSERVED IN A SECTION 4·0 FT. U/S OF THE EXIT END ALONG VERTICAL 0·15 FT. FROM THE CENTRE OF THE FLUME AND 0·33 FT. FROM THE GLASS SIDE. THE BED WAS ALSO GLASS

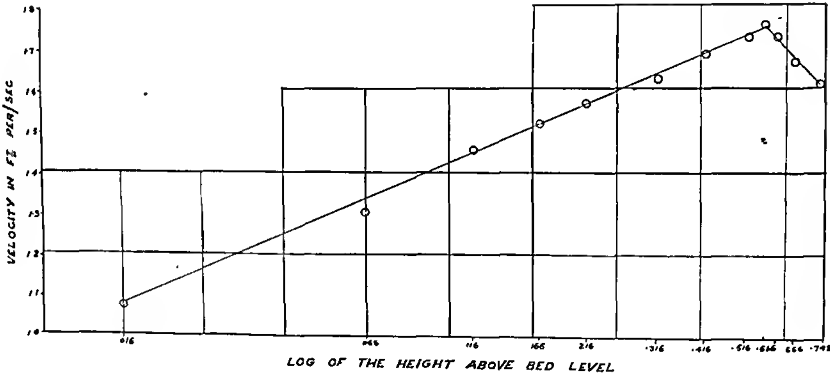


FIG.36

DISCHARGE 1 CUSECS

VELOCITIES OBSERVED IN A SECTION 4·0 FT. U/S OF THE EXIT END ALONG VERTICAL 0·2 FT. FROM THE CENTRE OF THE FLUME AND 0.28 FT. FROM THE GLASS SIDE THE BED WAS ALSO GLASS

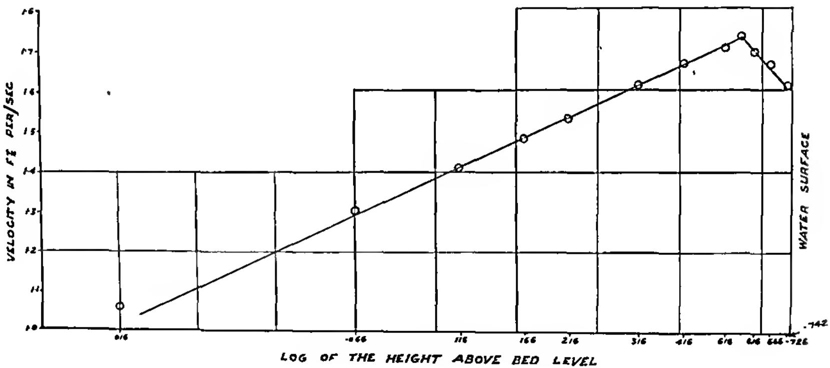


FIG.37

DISCHARGE 1 CUSECS

VELOCITIES OBSERVED IN A SECTION 4·0 FT. U/S OF THE EXIT END ALONG VERTICAL 0·3 FT. FROM THE CENTRE OF THE FLUME AND ·18 FT. FROM THE GLASS SIDE. THE BED WAS ALSO GLASS

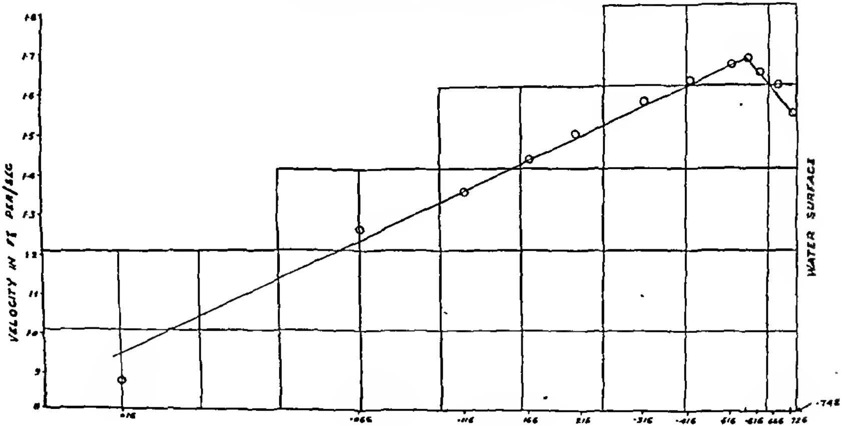


FIG. 38

DISCHARGE 1 CUSECS

VELOCITIES OBSERVED IN A SECTION 4·0 FT. U/S OF THE EXIT END ALONG VERTICAL 0·35 FT. FROM THE CENTRE OF THE FLUME AND 0·13 FT. FROM THE GLASS SIDE. THE BED WAS ALSO GLASS

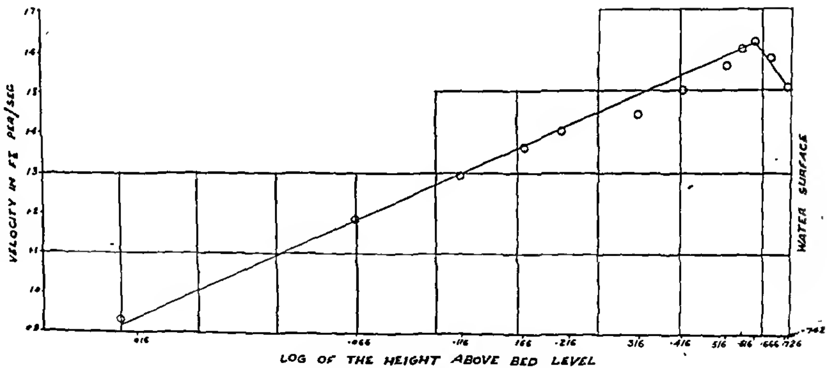
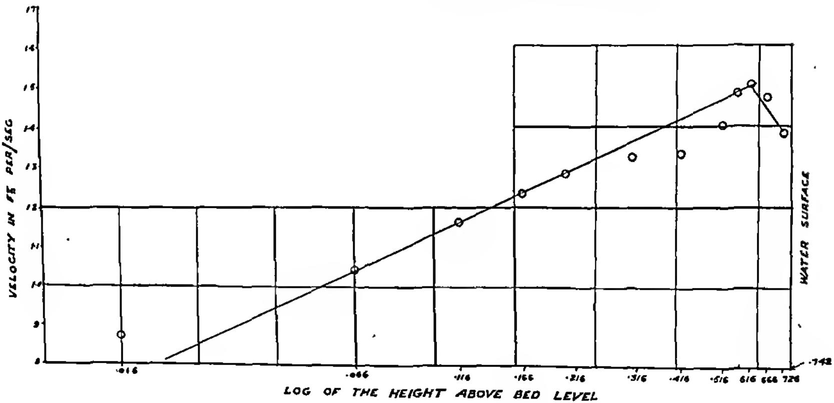


FIG. 40

DISCHARGE 1 CUSECS

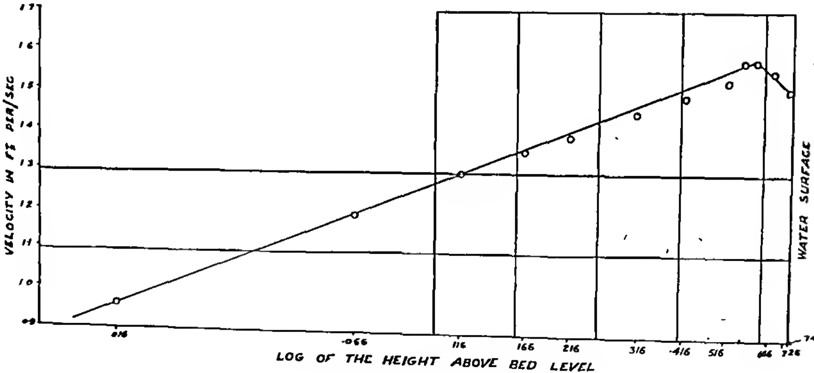
VELOCITIES OBSERVED IN A SECTION 4·0 FT. U/S OF THE EXIT END ALONG VERTICAL 0·45 FT. FROM THE CENTRE OF THE FLUME AND 0·03 FT. FROM THE GLASS SIDE. THE BED WAS ALSO GLASS



DISCHARGE 1 CUSECS

VELOCITIES OBSERVED IN A SECTION 4·0 FT. U/S OF THE EXIT END ALONG VERTICAL 0·4 FT. FROM THE CENTRE OF THE FLUME AND 0·08 FT. FROM THE GLASS SIDE THE BED WAS ALSO GLASS

FIG.39



STATISTICAL SECTION.

1. Analysis of Data obtained from Institute Experiments on Tube Well Models.

(a) *Relation between 'Drawdown' and Discharge.—(i) Object.—* a series of experiments carried out by the Physics Section of the ... le for the Officer on Special Duty, Tube-well Investigation, the ...barges obtained were observed for varying diameters of the ... r and depths of water in the well. For each case where the ... r two quantities had fixed values the discharge (measured in cubic ... etres per second) was plotted as ordinate against the drawdown ... easured in centimetres) as abscissa, and the plotted points joined by a ... ooth curve. Twelve such curves were prepared and attached to ... e report on 'Tube-well Experiments'.

These curves, in general, showed a more than proportionate ... se in discharge for increases in drawdown. Thus if the first ... served point (for the lowest drawdown) was joined to the origin ... automatically lay on the curve, as the discharge for a zero ... down is zero) and the line joining them produced, the other points the curve were seen to lie above this line. It was at first considered ... the slope of the line would, for the comparatively small drawdowns ... ly to be met with in practice, give a fair idea of the ratio of the dis... to the drawdown. This consideration was based on the usual ... tion that the discharge is, under given conditions of depth of ... the well and strainer diameter, directly and linearly proportional ... the drawdown. In other words, if Q be the discharge and H the ... own, it is taken that—

$$Q = c.H$$

...here c is a constant, so long as Q and H alone vary.

The departure from this linear relation in the case of experimental ... urves was believed to be, in some measure, due to the finite radius ... the boundary taken in the experiments as representing the region ... influence of the tube-well ; and as nine of the twelve curves had a ... nt radius of influence to the remaining three, this point was ... o be examined carefully. In this connection it was suggested by the ... fficer on Special Duty, Tube-well Investigation, that the slope of the ... ngent at the origin to these curves might serve as a measure of dis... tion. He also considered that this tangent was not likely to have ... he same slope as the line mentioned above as joining the origin to the ... st observed point.

The analysis of these curves by fitting suitable formulæ by statistical methods was carried out at the request of the Tube-well Investigation Officer.

(*ii*) *Method of analysis.*—As the origin was a point on each Q-I curve, and as the departure from a straight line law was marked, i was considered that a relation of the form—

$$Q = c_1 H + c_2 H^2 \quad .. \quad .. \quad (1)$$

would be suitable. A more complex formula was ruled out in vie of the small number of actually observed points available in some the cases, and the necessity for adhering to the same form in all t cases.

The values of c_1 and c_2 were found by the method of successi differences, with such small adjustments as appeared to be necessa for points slightly off the smooth Q-H curve.

From (1) it was easily seen that on differentiation,

$$dQ / dH = c_1 + 2 c_2 H \quad .. \quad .. \quad (2)$$

As dQ/dH gives the slope of the tangent to the Q-H curve at any point it is obvious that the slope of the tangent at the origin is given by—

$$(dQ/dH)_{H=0} = c_1 \quad .. \quad .. \quad (3)$$

Hence the value of c_1 gives at once a rough idea of the ratio of the discharge to drawdown for very small values of the latter for any given curve. If this is compared with the slope of the line joining the origin (0,0) to the first observed point (Q_1, H_1), the validity of the adoption of this slope as the discharge-drawdown ratio for small values of drawdown is tested.

(*iii*) *The Formulæ. Comparison of actual and calculated values.*—The following table shows the values of c_1 and c_2 in formula (1) for varying R (radius of boundary), D (depth of water in well) and S (strainer-diameter). All the three quantities are measured in c.m.—

Curve No.	R.	S.	D.	c_1	c_2
1	50	5	9·4	·464	.0088
2	50	5	11·9	·536	·0064
3	50	5	14 5	·620	·0040
4	50	7·7	9·4	·508	·0096
5	60	7·7	11·9	·574	·0104
6	60	7·7	14·5	·640	·0112
7	50	10·1	9·4	·620	·0160
8	50	10·1	11·9	·656	·0096
9	50	10·1	14·5	·758	·0104
10	100	15 2	12·7	1·420	·0280
11	100	15·2	20·3	2·080	·0180
12	100	15·2	30·5	2·666	·0143

The actually observed values of Q are compared with the cal-
' in the following tables, separately for each curve :—

TABLE 17.

—	H.	Q (actual).	Q (calculated).	Difference.
No. 1	2·5	1·20	1·22	—·02
	5·0	2·48	2·54	—·06
	7·5	4·03	3·98	·05
	10·0	5·59	5·52	·07
	12·5	7·20	7·17	·03
	15·0	8·85	8·94	—·09
No. 2	2·5	1·44	1·43	·01
	5·0	2·94	2·94	*Nil.*
	7·5	4·52	4·53	—·01
	10·0	6·23	6·20	·03
	12·5	7 98	7·95	·03
No. 3	2·5	1·58	1·59	—·01
	5·0	3·20	3·23	—·03
	7·5	4·94	4·92	·02
	10·0	6·68	6 66	·02
No. 4	2·5	1·30	1·33	—·03
	5·0	2·72	2·78	—·06
	7·5	4·36	4·35	·01
	10·0	6·10	6·04	·06
	12·5	7·85	7 85	*Nil*
	15·0	9·76	9 78	—·02
No. 5	2·5	1·51	1 50	·01
	5·0	3·15	3·13	—·06
	7·5	4 57	4·59	— 02
	10·0	6·78	6 78	*Nil.*
	12·5	8·52	8 50	·02
No. 6	2·5	1·68	1·67	·01
	5·0	3·50	3·48	·02
	7·5	5·43	5·43	*Nil.*
	10·0	7·52	7·52	*Nil.*

(*iv*) *Deductions.*—(1) It is obvious that the linear relation is inadequate and the quadratic fairly accurate for expressing the 'discharge-drawdown' relation, *as far as these* 12 *curves are concerned.* Whether this is due to the fact that the flow increases more rapidly than the head or is due to some unknown factors or errors cannot be discovered from the data.

(2) The relation between Q and H takes, for constant conditions, the form—

$$Q = c_1 H + c_2 H^2 \qquad .. \qquad .. \quad (1)$$

with an accuracy of 3 per cent. or higher. The formulæ are collected together in the following table. (The figures in brackets refer to curve Nos.).

(*a*) BOUNDARY RADIUS=50 c.m.

DEPTH OF WATER IN THE WELL.	DIAMETER OF STRAINER.		
	6 c.m.	7·7 c.m.	10·1 c.m.
9·4	·464 H + ·0088 H^2 (1)	·608 H + ·0096 H^2 (4)	·520 H + ·0160 H^2 (7).
11·9	·556 H + ·0064 H^2 (2)	·574 H + ·0104 H^2 (5)	·656 H + ·0096 H^2 (8).
14·5	·626 H + ·0040 H^2 (3)	·640 H + ·0112 H^2 (6)	·758 H + 0104 H^2 (9).

(*b*) BOUNDARY RADIUS=100 c.m.

DEPTH OF WATER IN THE WELL.	DIAMETER OF STRAINER = 15·2 C.M.
12·7	1·420 H + ·0280 H^2 (10).
20·3	2·080 H + ·0180 H^2 (11)
30·5	2·666 H + ·0143 H^2 (12)

They show that the co-efficient of H (which is the limiting value of the discharge-drawdown ratio for very small drawdowns) increases with the depth of water in the well and with the diameter of the strainer. But doubling the diameter increases this index by between 12 and 20 per cent. only.

Similarly an increase in the depth of water is not reflected by a proportionate rise in the value of the index, which is increased by amounts varying from 25 to 50 per cent., when the diameter rises from 9·4 c.m. to 14·5 c.m: in case of the three groups in (*a*).

(3) The co-efficient of H^2 does not appear to be very clearly associated either with variations in depth of water or with the changes in strainer diameter.

(4) The boundary effect is not evalnable as the other conditions, as also the porosity of the sand, are different in the two cases.

(*v*) *Discharge-Drawdown Ratio.*—The following table shows the slopes of the tangent at the origin and of the line joining the origin to the first observed point for each of the twelve curves :—

Curve No.	C_1	Slope of the line joining the origin to the first point.	Difference.
1	·464	·480	—·016
2	·556	·576	—·020
3	·626	·632	—·006
4	·508	·520	—·012
5	·574	·604	—·030
6	·640	·672	—·032
7	·520	·552	—·032
8	·656	·660	—·004
9	·758	·768	—·010
10	1·420	1·556	—·136
11	2·080	2·123	—·043
12	2·566	2·704	—·038

It is thus seen that the slope of the line joining the origin to the first point gives a value higher than c_1 ; the difference, however, being, except for one case, nowhere greater than 5 per cent. of the correct value of c_1. For ordinary purposes for which c_2 is not to be introduced, the difference is probably negligible.

(*b*) *Relation between 'Discharge-Drawdown Ratio' and 'Length of Strainer' i.e., depth in the well.*—(*i*) *Object.*—The Officer on Special Duty, Tube-well Investigation next requested the relation between the 'Discharge-Drawdown ratio' (Q/H) and the depth of strainer (D) to be studied. The general belief is that the two should be linearly connected.

(*ii*) *Analysis.*—The data were re-arranged in fifteen groups for each of which the values of R (Boundary radius), S (Strainer diameter), and H (Drawdown head) were the same. The values of

Q/H were calculated within each group and plotted against, as also divided by, D. It was noticed that in each group Q/HD decreased as D increased, and though it appeared that the relation could be adequately described by a formula of the form—

$$Q/H \text{ (H constant)} = a_1 D - a_2 D^2,$$

where a_1, a_2 were positive quantities, constant for a given 'drawdown' it was considered that *the limited quantity of data given by the experiments necessitated this conclusion to be accepted only after actual verification in the field.*

(iii) *Conclusion.*—The discharge from a tube-well per unit depth of strainer per unit drawdown decreases, for a given drawdown, as the depth of strainer is increased. (Provided the boundary radius, strainer diameter and transmission constant of the medium do not vary).

(c) *Summary.*—The discharge from a tube-well model increases more rapidly than drawdown and less rapidly than length of strainer. At very small drawdowns the discharge can be taken as directly proportional to drawdown, other conditions being the same. *The conclusions are subject to verification in the field.*

2. Rise of water table in the Rechna Doab (Lower Half).

(a) *Object.*—It was remarked by one of the Chief Engineers that high correlation co-efficients between the rate of rise of water-table and the rainfall over any given area were explicable as being caused by the sensitivity of the high water-table in those areas to the fluctuations of annual rainfall, and that low co-efficients might be expected in the areas where the water-table is at a greater depth from the natural surface.

The lower part of the Rechna Doab was selected for investigation, as the water-table in this area is not close to the surface and the mean annual rainfall is not so high as in some of the other areas previously investigated. This was expected to give some test of the other common belief as to the high co-efficients being caused by the largeness of the annual rainfall.

(b) *The Statistical Analysis.*—(i) *The Data.*—Daily rainfall figures were obtained for 17 regularly observed rain gauge stations lying in the tract bounded by the rivers Ravi and Chenab downstream of a line roughly joining Pindi Bhattian, Sangla and Kot Naubahar. (This line is believed to approximately coincide with the subterranean ridge located across the doab by the Gravity Survey party of the Institute). The arithmetical mean of these stations was taken as representative of the average rainfall over the area, and the average values grouped to give 5 days' totals for subsequent treatment.

The average rate of rise (δd) was obtained by taking the A. M. of the rises recorded from June to June in each of the 93 selected observation wells.

The period covered hy the investigation was 1905-06 t 1936-37.

(*ii*) *The calculations.*—The trend in the values of the annua rate of rise of water-table was found hy fitting a fifth degree poly nomial curve to the annual valnes. This curve is shown in Fig. 41.

The departures of the annual rise from the slow change curv were obtained as the variations to be accounted for in terms of flu tuations of annnal rainfall. ($\delta d_{\text{actual}} - \delta d_{\text{poly}}$:)

The five day totals of average rainfall were reduced to th six variates a′, b′,........f′, which are the co-efficients, for any give year, of the various terms in a timo series designed to express th seasonal changes of the rainfall.

The rate of rise measured from the slow change curve as th reference curve was correlated with the corresponding values, for the 32 years, of the rainfall variates, and the multiple correlation an percentage variance calculated to find the extent of the association the rate of rise and the variations of rainfall.

The regressions of the rate of rise on the variates were reduc so as to givo the mean monthly effects of the changes produced in t rate of rise by unit departures of the rainfall in the given months fro the mean values, for all the years, of those months.

(*iii*) *Discussion of results.*—(1) The slow change curve in Fig. can obviously be divided into two parts. The first part which cov about 14 years from 1907-08 to 1919-20 shows a gradual decrease the annual rate of rise from about 1·5′ to ·75′. The second part the curve from 1920-21 to 1936-37 is remarkably straight with a co stant value of about ·75′. It is interesting in that; firstly, in no otl area has such a straight portion been obtained for such a long period about 18 years, and secondly the ordinate does not tend towards ze as would be expected from tho behavionr in other cases.

In this connection similar curves were worked out for Low Chenab Canal (Upper half) and Upper Chenab Canal. In none of the cases has the riso steadied. A correlation between the slow chan curves for the two halves of tho Lower Chenab Canal gave a co-efficie of ·981, showing inter-connection of the rises in tho two areas.

(2) The regression curvo for the tract was slightly unusual showing a high maximum in winter months. This was explained b the very scanty rainfall in these months.

The average regression for July, August and September, taken together was about ·8. An extra inch of monsoon thus apparently sends up the annual rate of rise by about four-fifths of an inch.

These three months contribute, between themselves, 7·45", *i.e.*, nearly $\frac{2}{3}$ of the total average annual rainfall of 11·14".

(3) The multiple correlation co-efficients and the percentage of sum of squares of the departure of the annual rate of rise from the slow change curve, which are explicable in terms of the variations of the rainfall are shown below for each of the three areas :—

Area.	Multiple Correlation.	Percentage Variance.
Lower Chenab Canal (Upper) .	·96	89
Upper Chenab Canal ..	·89	78
Lower Chenab Canal (Lower) ..	·90	75

(*iv*) *Conclusions.*—(1) There is a high degree of correlation between rainfall and rise of water-table in the lower half of the Rechna Doab, where the water-table is fairly deep and the rainfall low. The suggested association of the high correlation with the high rainfall or high water-table is not supported by this particular area.

(2) The water-table in this area is rising at a steady rate of 9" per year for the last 18 years. This rate of rise shows no signs of slackening.

(3) The slow change curves in Lower Chenab Canal (Upper) and Lower Chenab Canal (Lower) are highly correlated indicating that either the upper area is affecting the lower or that similar factors are operating in both the cases.

3. Verification of P-Q and R-Q Relationships from Channels in Gujranwala Division.

A hydraulic survey of the channels in Gujranwala Division was carried out in Kharif, 1937 and the results received in the institute in the year under report. The data were calculated and checked and the hydraulic elements evaluated.

The formulæ—

$$P = 2·8\ Q^{1/2}$$

$$\text{and } R = ·47\ Q^{1/3}$$

were tested *against the data.*

The following table shows the names of some of the channels with R. D.'s and dates of observations, and the values of Q, R (actual) and R (calculated). The original list contains [illegible] channels and is, therefore, not reproduced in full

TABLE 18.

Comparison of actual values of Hydraulic Mean Radius with those calculated from the Formula, $R = \cdot 47\ Q^{1/3}$ for certain sites observed in Gujranwala Division in Kharif, 1937.

Serial No.	Name of Channel	R. D.	Date of observation.	Q (cusecs).	R (feet). Actual.	R (feet). Calculated.
1	Nurpur Distributary .	5,000	11-9-37	448	3·38	3·60
3	Rurala Minor .. .	500	Not given	21	1 39	1·30
5	Kila Mian Singh Minor .	19,000	Do	54	1·73	1·78
7	Ladhewala Minor ..	500	Do.	13	·92	1·10
8	Dhariwal Minor ..	500	Do.	3·8	·62	·73
14	Nurpur Distributary ..	124,000	Do.	66	1·95	1·90
17	Naushehra Distributary .	Head	Do.	470	3·70	3·67
21	Ditto	97,825	23-6-37	148	2·26	2·49
22	Mangoki Minor .	650	30-6-37	35	1 68	1·54
38	Mukta Minor	850	28-9-37	42	1·46	1·63
41	Naushehra Distributary .	130,206	15-9-37	87	2·09	2·08
44	Waran Minor ..	1,200	15 9-37	57	1 72	1·80
47	Kuthiali Minor .	59,000	2-10-37	27	1·39	1·41
48	Kakargil Sub-Minor .	1,000	24-10-37	10	1 16	1·25
53	Shahoki Sub-Minor .	1,000	26-10-37	20	1·18	1·28
56	Kuthiali Minor .	12,500	26-10-37	93	2·25	2·13
59	Sheikhupura Distributary ..	1,000	13-10-37	250	3·06	2·96
62	Ditto .	88,000	13-8-37	96	2 02	2·15
64	Ditto .	129,000	17-8-37	41	1·66	1·62
69	Jiwanpura Distributary ..	Head	15-9 37	14	1·19	1·13
71	Kurlke Minor ..	Do.	20-10-37	33	1·56	1·51
75	Tur Minor ..	Do	2-8-37	20	1·18	1·27
76	Sheikhupura Distributary ..	33,750	5-9-37	185	2·73	2·68
81	Harder Minor ..	Head	5-9-37	13	1·03	1·10

The logarithmic plotting of the values of Q, of R (observed) and of the formula $R = \cdot 47Q^{1/3}$ is shown in Fig. 42.

The following table shows the values for P (actual) and P (calculated), with names and R. D's. of some of the channels :—

TABLE 19.

Comparison of actual values of Wetted Perimeter with those calculated from the Formula, $P = 2{\cdot}8\ Q^{1/2}$, for some of the sites observed in Gujranwala Division in Kharif, 1937.

Serial No.	Name of Channel.	R. D.	Date of observation.	Q (cusecs).	P (feet).	
					Actual.	Calculated.
1	Nurpur Distributary ..	5,000	11-9-37	448	54·3	69·3
4	Kila Mian Singh Minor .	500	Not given	76	22 7	24·3
7	Ladhewala Minor .	500	Do.	13	9·8	10·1
10	Oobindpur Minor ..	500	Do.	81	21 4	25·2
13	Argan Minor ..	750	Do.	93	23·8	26·9
16	Nurpur Distributary ..	151,000	Do.	16	11·3	11·3
19	Naushehra Distributary ..	25,000	30-6-37	358	40·8	63·0
22	Mangoki Minor .	650	30-6 37	35	14·4	18·7
25	Naushehra Distributary ..	72,750	31-7-37	203	40·5	39·9
28	Mukta Minor ..	850	30-7-37	34	20·4	16·4
31	Naushehra Distributary ..	97,825	18-8-37	140	38 4	33·2
34	Ditto ..	25,000	28-9-37	372	40·9	54·0
37	Mangoki Minor ..	650	28-9-37	42	15·4	18·1
40	Naushehra Distributary ..	130,206	16-8-37	85	28·4	25·9
43	Waran Minor ..	1,200	16-8-37	52	22·4	20·2
46	Kuthiali Minor .	59,000	28-8-37	24	15·2	13·8
49	Kakargil Sub-minor ..	1,000	2-10-37	18	9·7	11·7
52	Shahoki Sub-minor ..	1,000	29-9-37	20	12·0	12·6
55	Kuthiali Minor ..	12,500	29-8-37	95	28·4	27·2
58	Ditto ..	1,250	25-10-37	117	28·6	30·3
61	Sheikhupura Distributary ..	1,000	27-10-37	242	44·5	43·5
64	Ditto ..	129,000	17-8-37	41	17·2	17·9
67	Kurlke Minor ..	Head	22-9-37	33	14 6	16·1
70	Sheikhupura Distributary ..	88,000	20-10-37	102	26·8	28·3
73	Jiwanpur Distributary ..	Head	17-10-37	12	9·4	9·7
76	Sheikhupura Distributary ..	72,500	2-8-37	135	29·1	32·5
79	Tur Minor ..	Head	5-9-37	20	13·2	12·5
82	Sheikhupura Distributary ..	39,750	16-10-37	183	38·5	37·9
85	Hardev Minor ..	Head	16-10-37	14	9·5	10·5

The logarithmic plotting of the values of Q, of P (observed) and of the formula $P = 2{\cdot}8\ Q^{1/2}$ in Fig. 43.

4. Statistical Examination of Seepage Losses on the Lower Chenab Canal System.

A committee was appointed by the Irrigation Branch to estimate the seepage losses on various branches of the Lower Chenab Canal system. The committee decided that the best method of estimation would be one in which the average monthly losses between observed sites on any branch, under steady conditions of supply, are worked out from existing discharge records for a number of years and studied by calculations of mean and probable error for the entire period. By knowing the losses in any given reach of the branch, the losses in its entire length were to be calculated on the assumption of proportionality.

The monthly losses for different reaches were worked out by the Discharge Division for a period of 20 years and their means and probable errors for these 20 years were calculated in the Institute. These were plotted so as to show for each channel the curve of mean monthly losses and the two curves showing mean *plus* or *minus* the probable error. The band formed by the latter two curves gave the interval in which the seepage losses may be expected to lie in half of the total number of years.

The probable error was usually found to be quite high as compared with the mean.

The analysis of the total variance for each channel into the components due to months, years and the residual variations was also carried out and it was found that in most cases the changes between months and from year to year could account for a significant proportion of the total variance. This analysis is now being extended.

5. Analysis of the Results of Run-off and Soil Erosion Experiments.

(a) *Object.*—Following the experiments at Madhopur, similar experiments were carried out by the Forest Department at Nurpur for verification of the harmful results of loss of plant cover as revealed by the former experiments. The matter is of interest to irrigation engineers in view of the possible association of soil erosion in the hills with higher floods in summer and reduced supplies in winter.

(b) *Data.*—Six trays were used in these experiments. Each tray had an area of 3,125 sq. cm. and the volume of water run off its surface was measured after each shower and expressed as a percentage of the total amount received during the shower. The soil eroded during the shower was weighed and expressed in terms of the soil that would proportionally be eroded from an acre. All the calculations were checked in the Institute.

(c) *Summary of the Data.*—The quarterly averages for the period July 1937 — December 1938, are shown in table 20 :—

TABLE 20.

Summary of the Results of Soil-Erosion and Run-off Experiments at Nurpur (July 1937—December 1938).

(a) PERCENTAGE RUN-OFFS.

Period.	Total rain.	Mean percentage run-off.					
		Trays.		*Trays*		*Trays*	
		1	2	3	4	5	6
		Grass.	Grass.	Grass and Scrub.	Grass and Scrub.	Bare.	Bare.
	Inches.						
1937.							
July—September ..	37·89	20·0	21·2	13·2	10·4	38·1	41·5
October—December ..	0·72	8·5	23·3	3·1	3·9	38·5	40·3
1938.							
January—March ..	10·91	15·8	32·1	7·5	6·6	42·4	51·0
April—June ..	0·01	15·4	13·3	4·1	10·6	49·7	53·1
July—September ..	30·31	11·2	12·3	9·1	8·5	60·3	62·0
October—December ..	·67	..	..	4·6	1·6	16·6	11·4
Total (18 months) ..	98·51	15·1	19·2	9·4	12·2	46·4	49·6

(b) MATERIAL ERODED (100 LBS. PER ACRE).

Period.	Total rain.	Total erosion of soil.					
		Trays.		*Trays.*		*Trays.*	
		1	2	3	4	5	6
		Grass.	Grass	Grass and Scrub.	Grass and Scrub.	Bare.	Bare.
	Inches.						
1937.							
July—September ..	37·89	29·5	36·6	33·1	42·7	169·9	209·4
October—December ..	9·72	1·5	4·0	·6	2·4	9·8	12·4
1938.							
January—March ..	19·91	3·4	4·5	1·5	1·2	9·4	12·3
April—June ..	9·91	3·1	6·0	2·7	3·3	51·9	45·5
July—September ..	30·31	3·9	5·5	7·2	4·9	229·2	156·1
October—December ..	·67	Not measured.					
Total (18 months) ..	98·51	41·3	56·6	45·1	53·7	461·2	435·8

(c) *Deductions.*—The above table shows that :—

(1) About half the water received as rainfall by a bare surface runs off and does not soak into the soil. [See table 20 (*a*), last entries of last two columns].

(2) About one-sixth of the water received by grass-covered land runs off its surface, while for land covered with grass and scrub the proportion is only one-tenth (see table 20 (a), last entries of columns under trays 1, 2, 3 and 4).

(3) Trays with similar cover—grass, or grass and scrub, or no cover—behave within limits, in a similar manner. (The dissimilarity of the behaviour of trays 1 and 2 is due to the width of the tray 2 being smaller than that of tray 1, and to some experimental errors).

(4) The different quarters of the year do not markedly affect the percentages of run-off.

(5) There is a gradual increase (leaving the last quarter out when there is little rain) in the proportionate run-off from the bare trays. In the first six months the run-off was about 40 per cent. of the water received, in the next six it was very nearly 50 per cent. and in the next quarter it jumped to 60 per cent.

The covered trays show no such changes.

(6) The bare trays lose soil, on an average, at about ten times (and sometimes more than ten times) the rate at which grass or grass and scrub covered trays lose it. The latter two types of cover do not appear to be unlike between themselves. [see table 20 (*b*), the totals of columns under trays 5, 6 ; 1, 2 ; 3 and 4].

(7) The greatest loss of soil is in the monsoon months whatever be the type of cover (see entries for July—September for all trays).

(8) It is possible for a bare acre of soil to lose, in 18 months, over twenty tons of surface material ; while the covered acre hardly loses two tons (see totals of columns under various trays in table 20 (*b*). The values have been changed to tons).

Diagrams showing the main features of the above data at a glance were prepared. These are reproduced in Fig. 44 (a) and Fig. 44 (*b*).

A complete statistical analysis has also been carried out. The results are being examined.

6. The Silt Problem.

Tho problcm continued to occupy the major place in the activities of the Statistical Section, and tho work dono can bo divided into the following parts :—

A.—KNOWLEDGE OF SILT MOVEMENT AS APPLIED TO DESIGN OF REGIME CHANNELS.

(a) *Checking, correction, tabulation and record of hydraulic data received from Research Overseers.*—(i) Most of the observation sites, which were being observed last year were closed towards the end of the present year, partly due to the transfer of overseers to other duties and partly due to enough data having been accumulated at each site. Again it was noticed that somo of tho regime formulæ in some cases fitted data collected from general surveys of a number of channels, whose regime was not establisbed by investigation. It was, therefore, necessary to examine such channels more carefully so as to fix attention only on such formulæ as were applicable to regime sites alone.

The disposition of the sites for the greater part of the year, however, was: Sagar, Nanuana, Kot Khudayar and Tawan (Lower Chenab Canal). About fifteen sites were observed daily at these stations and the forms containing the discharge data were sent to Lahore. All these forms were checked in the Statistical Section and the mean depth, bed widtb, and Kennedy's critical velocity ratio were calculated and checked. Tho discharge elements were then tabulated sepsrately for each site and the mean values were calculated after every month, any days of low or fluctuating supplies being omitted.

(ii) The extended rating tables showing velocities at intervals of one second for varying numbers of revolutions for the newly supplied or re-rated current-meters were prepared and sent out to the overseers. This enabled a check to be exercised here on the velocities shown and guarded against any wrong interpolation by the overseer.

(b) *Calculations for silt size distribution curves.*—(i) Each of the overseers, took, on an average, one or more bed silt samples every week from each of the channels under his observation. These samples, after analysis by the optical lever siltometer, gave pressure-time measurements, which were reduced to give the percentago distribution of particles according to their sizes.

(ii) A large number of the samples received from other sources were analysed by the Puri siltometer, which gives the weights of the particles of various sizes present in the sample. The percentago distributions were calculated for all these samples also.

Altogether nearly fifteen hundred samplos were so treated.

(*iii*) The constants m (weighted mean size) and σ (the standard deviation, which measures the dispersion of other sizes about the mean size) were calculated from the percentage distribution for each sample.

(*c*) *Correlations for connecting silt movement with the design of channels.*—The relations obtained by correlating the silt characteristics and the hydraulic elements are described in the report for the last year. No new correlations were undertaken during the year.

(*d*) *Recording of temperature and silt in suspension at the Overseer's sites.*—(*i*) The hydrometers which are designed for reading the silt in suspension are calibrated in the laboratory before issue and recalibrated if they or the thermometers are damaged in use. The corrections to be applied to the readings are obtained for a few temperatures and the resulting curve is utilized by the Statistical Section for interpolating values at intervals of 0·1°C from 9°C to 35°C.

Such correction tables for more than 20 hydrometers were prepared during the year.

(*ii*) The amounts of the silt suspended per litre of water as determined by the hydrometers, and also the temperature of the canal water were tabulated separately for each overseer's site for each day. The mean temperature was calculated for each month.

B.—KNOWLEDGE OF SILT ENTRY INTO CANALS AS AFFECTED BY THE SUPPLY AND REGULATION AT THE HEADWORKS.

The volume and gradation of silt entering the canals through the head regulators under varying conditions of river supply and headworks regulation was determined by analysts stationed at the main headworks of the province. The relation of river and regulation conditions to the entry of silt was studied for the Ferozepur headworks and a report submitted to the department.

FIG. 41

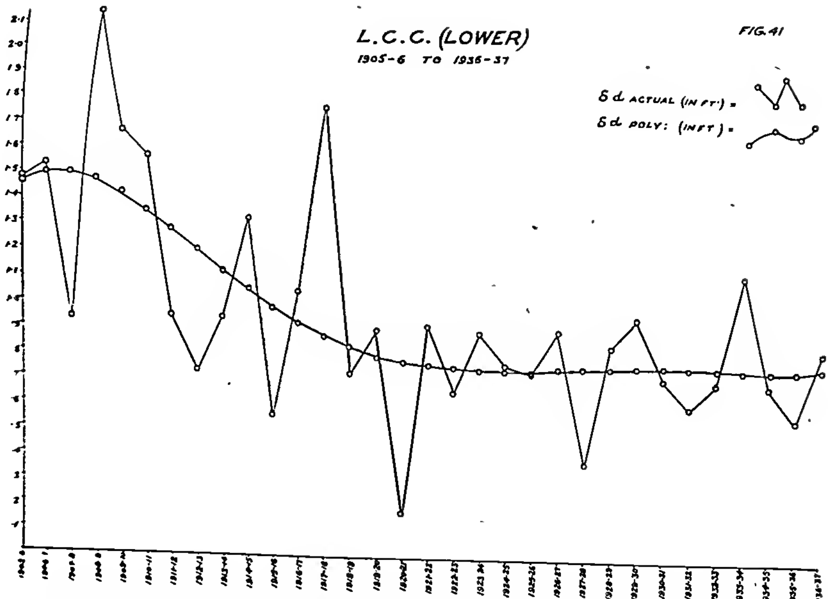
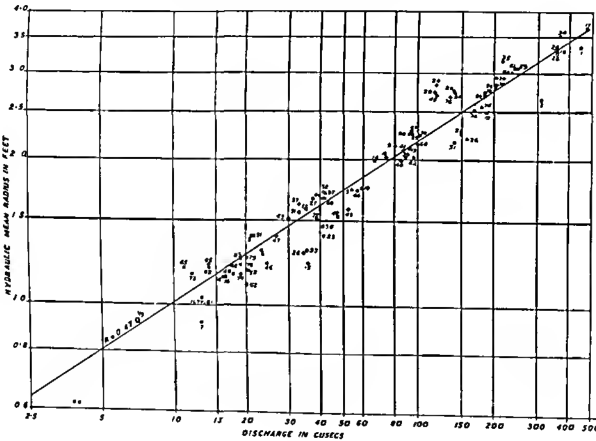


FIG. 42

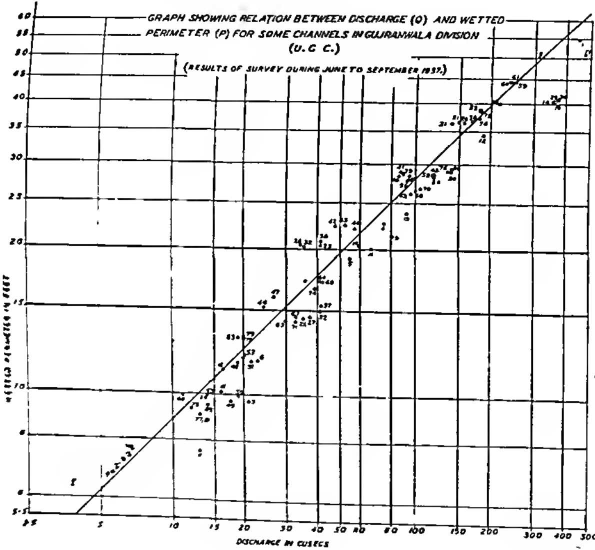
GRAPH SHOWING RELATION BETWEEN DISCHARGE (Q) AND HYDRAULIC MEAN RADIUS (R) ON SOME CHANNELS IN GUJRANWALA DIVISION (U. C. C.)

(RESULTS OF SURVEY DURING JUNE TO SEPTEMBER 1937)



N.B. THE NUMBERS 1, 2, REFER TO THE SERIAL NUMBERS IN THE ATTACHED LIST OF CHANNELS.

FIG.43



N.B. THE NUMBERS 1, 2, ... REFER TO THE SERIAL NUMBERS IN THE ATTACHED LIST OF CHANNELS

FIG. 44 A

RESULTS OF SOIL-EROSION & RUN-OFF EXPERIMENTS AT NURPUR.

(JULY 1937-DEC. 1937)

SCALE VER: 1 CM = 10"

AT A GLANCE

(a) RUN OFF

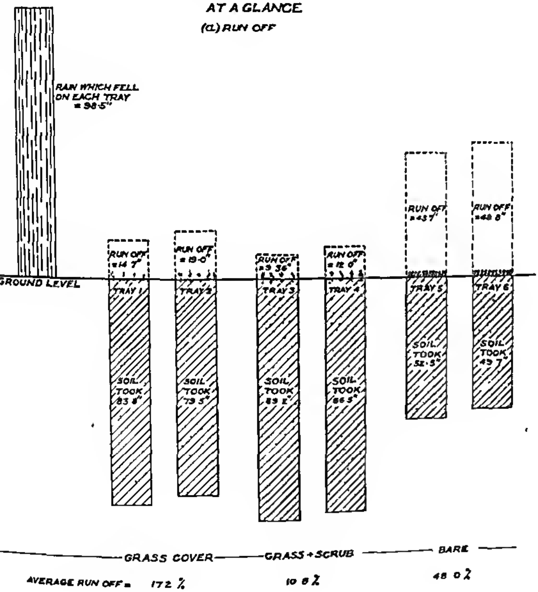
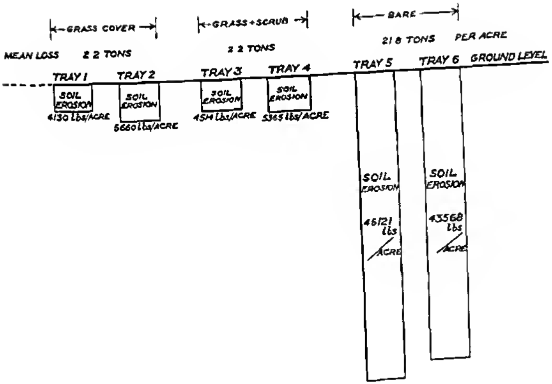


FIG. 44 B

(6) EROSION

SCALE VER 1CM = 2000 lbs



HYDRAULICS SECTION.

Tho work in the Hydraulic Section has been concerned with river training, the design of regulators, the reconditioning of existing works, the examination of rigid modules and silt investigations. The larger models were studied at the River Research Station at Malikpur and the smaller models in the flumes and trays at Lahore.

The Prevention of the Erosion of the River Banks Below Panjnad Headworks.—Erosion downstream of the Panjnad Headworks had been taking place on the left bank and had severed the flood embankments. Retired embankments had been constructed but these were also heavily attacked and an attempt was made by pilchhi protection to hold them up. This erosion, as well as a heavier one on the right bank of the river, was considered to be the result of the formation of a large bela downstream of the centre of the weir. The left channel of the river was taking about one-third of the total discharge and the right channel two-thirds. If the erosion continued the protection of the station area and buildings would become very expensive. It was, therefore, considered necessary to hold the river in its present position and an investigation was commenced to determine the most suitable method by which this result might be obtained.

A model of the river for a distance of one mile upstream of the weir, that is to the confluence of the Rivers Sutlej and Chenab, and 5½ miles downstream of the weir was constructed in the tray. The following scales were adopted :—

Horizontal Scale	..	..	.. 1/750
Lateral Scale	..	..	.. 1/750
Vertical Scale	..	..	.. 1/100

The discharge scale was calculated according to Froude's formula and the time scale was fixed at one hour on the model being equivalent to one month on the prototype. One cubic foot of sand was added per hour in order to maintain bed equilibrium.

Cross Sections of the river downstream of the Headworks were available for 1936 and 1937. The model was moulded to the 1936 cross sections and the discharges for the rabi 1936-37 and for the kharif 1937 were run. On the completion of this run a survey of the bed was made and compared with the cross sections for 1937. It was found that there was a very close agreement between the model and the prototype.

During 1938, observations were made on the current directions downstream of the weir in both arms of the river. The development of the left bank erosion was also recorded. The model baving been run for the 1937 discharges was now continued witb those of 1938 and the current directions, velocity observations and bank erosion recorded. The current directions for both the prototype and the model for similar conditions are shown in Figs. 45 and 45-A. A comparison of ths two diagrams shows thot there is close agreement.

Fig. 45 also shows the bank conditions after the run for 1938. It will he seen that the dowel bund and the left embankment have been washed away and only the new retired embankments remain. This agrees with the results obtained at Panjnad by the 1938 flood season.

Velocity observations were made in the left channel and it was found tbat tbe bighest velocity occurred near the bund. This bad also heen reported to he the case during 1938 at Panjnod.

Suggestions had been made regarding the protection of the bank by spurs. The following were investigated :—

(A) An extension of the downstream left guide bank.

(B) The construction of a ' T '-headed spur at R. D. 6,500.

(C) The construction of two spurs at R. D's. 3,500 and 6,500 downstream of the weir.

A.—*The extension of the left guide bank.*—Tbe left guide honk was extended for a distonce of 2,000 feet. The moximum action on tbo prototype during 1938 had been found to occur when the discharge wos 150,000 cusecs during o period of 25 days. Accordingly, to test the effect of the oxtension of the guido bank, a dischorge equivalent to 150,000 cusecs was run. Current directions wero observed ond the erosion of the bank wos stndied. The results ore shown in Fig. 46. Tho following conclusions wero drawn from this test :—

(*a*) Tho flow occurred olong the banks for a distance of 1,500 feet downstreom of the oxtended guide hank.

(*b*) A slight flow occnrred along tbo hank botwcen 3,500 feet, and 5,500 feet downstreom of tho weir line.

(*c*) Tho crosion of tho left bank at 7,500 feet downstream of the weir line is much moro severe witb the extended guido bank thon it wos with tho originol.

(*d*) As the experiment progressed, it was noticed that a larger proportion of the discharge tended to flow in the left channel.

It was concluded that the extension of the guide bank did not afford the amount of protection required.

B.—*Construction of a 'T'-headed spur at R. D.* 6,500.—A 'T'-headed spur was constructed at R. D. 6,500. The nose of the spur was situated at the higher part of the bela and the deep channel was closed. Similar river conditions to those in test A were run. The results are illustrated in Figs. 47 and 48. It will be seen from this figure that as a result of the construction of the spur :—

(*a*) The water flowing through bays 4 and 5 now enters the right channel.

(*b*) The flow from the bays on the left side of the weir takes a course round the nose of the spur well away from the left bank.

(*c*) Upstream of the spur there is reverse flow but the velocity is low.

(*d*) Downstream of the spur there is a large area in which reverse flow is taking place.

The conclusion reached as a result of this test is that the spur forces a large portion of the supply into the right channel causing much greater action on that bank.

C.—*The construction of two spurs at R. D.'s* 3,500 *and* 6,500 *downstream of the weir.*—The noses of both these spurs were situated in the deep channel. The result of this test is shown in Fig. 49. The observations show that the construction of two spurs results in the main current in the left channel being kept well away from the river bank for a distance of 9,000 feet downstream of the weir.

The preliminary experiments having shown that the most suitable method of protecting the bank was the construction of two 'T'-headed spurs, the investigation was continued to determine :—

(*a*) The optimum length of the spurs and the optimum distance between them.

(*b*) The most suitable shape of the spurs.

(*c*) The optimum length of the head of the spur.

In each test the model was run with a discharge equivalent to 200,000 cusecs for a period of two hours.

(*a*) *Investigation of the length of the spurs and the distance between them.*—The position of the first spur was fixed at R. D. 3,500 **below** the weir line and the position of the second spur was raised.

first series of tests the spurs projected into the river for a distance of 700 feet. The results are shown in Table 21 in which l is the length of the spur and d the distance between the spurs.

TABLE 21.

Distance between the spurs.	$\frac{d}{l}$	Conditions of flow between the the spurs.	Attack on the D/S of the 2nd spur.
1,500′	2·15	Main flow at a distance from the bank. Dead water near the bank.	Attack D/S of the 2nd spur.
2,000′	2·86	Main flow at a distance from the bank. No flow near the bank.	Attack a little further downstream.
2,500′	3·57	Very low velocity near the bank.	Still a little further downstream.
3,000′	4·29	Low velocity near the bank	Attack very far downstream.
4,000′	5·72	Main flow gets nearer to the bank.	Definite kick away from the bank.

Fig. 50 shows the directions of flow of the main current for some of the above cases.

From Fig. 50 and the results in Table 21, it will be seen that when $d/l = 2{\cdot}15$ there is a severe attack on the bank immediately downstream of the second spur. When $d/l = 2{\cdot}86$, the current upstream of the first spur is deflected away from the bank but again attacks the bank not far from the second spur. When $d/l = 4{\cdot}29$, there is no attack on the bank for a considerable distance downstream of the second spur. In the case of $d/l{=}5{\cdot}72$, the river having passed the first spur tends to approach the bank in between the spurs and the velocity near the bank is high. It was concluded, therefore, that when $d/l = 5{\cdot}72$, the distance between the spurs was too great to afford the maximum protection. The most satisfactory result is obtained when the ratio d/l is between 4 and 5.

The experiments were now repeated with the length of the spurs 500 feet. The results are shown in Table 22 and illustrated in Fig. 51.

TABLE 22.

Distance between the spurs.	$\frac{d}{l}$	Conditions of flow between the spurs.	Attack on the D/S of the 2nd spur.
1,500	8	No attack. Very low velocity.	Attack near the D/S of 2nd spur.
2,000	4	No attack. Low velocity	Attack is at a little distance D/S.
2,500	5	No attack. Low velocity along the bank.	Attack still D/S.
4,000	8	Definite attack at 1,500′ U/S of 2nd spur.	Attack very far D/S.

The results show that 500 feet spurs are as effective as the 700 feet spurs when the distance between them is such that $d/l = 5$.

Further tests were now carried out with spurs 300 feet in length and it was found that they were not so effective as spurs 500 feet in length.

(b) *Investigation of the most-suitable shape of the spurs.*—Various types of spurs were suggested for investigation and the following were examined :—

(*i*) Straight spur.
(*ii*) Hockey spur.
(*iii*) Inverted hockey spur.
(*iv*) 'T'.—headed spurs.

The measurement taken for comparison was the depth of scour at the nose of the spur. The results are shown in Table 23.

TABLE 23.

Shape of spur.	Maximum scour measured from a fixed datum of 340 R. L.
Straight spur	30·7
Hockey spur radius 500′	35·0
Inverted Hockey Spur	26·0
'T.'-Spur Head = 500	27·2

It will be seen that the least scour is obtained with the inverted hockey spur. In this case, however, there was a much greater draw of water along the upstream face of the spur than in any other type. The depth of scour with a 'T'-/. headed spur is slightly greater than with the inverted hockey spur but it is located at the upstream nose of the spur and it is not so extensive. The 'T'-/. headed spur was selected for further examination.

(c) *Determination of the optimum length of the head of the spur.*—The results of varying the length of the head of the spur are shown in Table 24.

TABLE 24.

Length of 'T'-Head of Spur.	Depth of Scour.			Distance D/S at which the main flow occurred along the left bank.
	U/S Nose.	T. Pivot.	D/S Nose.	
500′	27·2	21·2	18·5	2,500′
400′	30·0	23·6	20·0	2,200′
300′	31·0	24·7	22·6	2,000′
200′	32·0	29·0	26·5	1,700′

From this table it will be seen that the shorter the head of the spur, the smaller is the distance protected downstream of the spur. The depth of scour along the head of the spur and at the downstream nose for the various cases is shown in Figs. 52 and 53. These figures show that as the length of the head of the spur becomes smaller, the depth of scour along the head becomes greater. A spur head 500 feet in length appears to be the most suitable for the protection of the bank and the stability of the spur.

The protection of the left bank of the river resulted in increased erosion of the right bank. An investigation was now started to determine the best form of protection from the right bank. The effects of single and double spurs were examined in a similar manner to that for the left bank and it was found that two spurs 500 feet in length afforded the greatest protection. Fig. 54 shows the final arrangement of the spurs recommended.

(2) *The training of the River Chenab above Khanki Headworks.*—Since the reconstruction of the weir certain changes have taken place in the river at Khanki due to alterations in the method of regulation. As a result of these changes certain difficulties in feeding the canal might arise and an investigation of the further course of events was ordered.

The weir at Khanki consists of the left, centre, right undersluices, and the shuttered bays. The Lower Chenab Canal takes off above the left undersluices. The Channel to the right undersluices has been over-developed with tho result that belas have extended in the left channel and it is now difficult to use Bay 4, the centre undersluices. If the right channel develops further there may be some difficulty in feeding the canal in times of low supply. The following are the main points submitted by the Chief Engineer for investigation—

(1) What is likely to happen to the main *bela* if the present methods of regulation are continued, and is a subsidiary *bela* likely to grow in the left channel?

(2) What should be done to obtain the greatest advantage from Bay 4?

(3) Is the right channel of the river drawing off more than its fair share of silt?

(4) What distribution of supplies in the two branches of the river will give the optimum silt entry into the canal in—

(*a*) Summer.

(*b*) Winter.

(5) How far the present silt ejector is performing its function of excluding coarse silt from the canal and what discharges should be passed through the silt ejector tunnels at different stages of the river for optimum results?

(6) What additions or alterations, if any, are required in the existing silt ejector to make it more useful?

(7) To investigate to what extent heading up of the supply at gauge number 13 helps to exclude silt from the canal?

The preparation and verification of the models was undertaken by the Mathematical Section and an account of the preliminary work will be found in the report of that Section. From this point the Hydraulic Section continued the investigation. The survey of the river and the lay-out of the model is shown in Figs. 55 and 56.

(*a*) *What is likely to happen to the main bela if the present methods of regulation are continued and is a subsidiary bela likely to grow in the left channel?*—The river bed was moulded to the 1938 cross-sections and the river conditions of 1937 were run. After the run a survey was made and an examination of the data disclosed the following :—

(*i*) The two small belas between spurs B. 2 and B. 3, disappeared and an embayment was found resulting in a severe attack at the nose of spur B. 3.

(*ii*) The two belas in front of the embayment betw spurs I. L. A. and G. H. U. A. formed into a la bela with channels on each side of the bela.

(*iii*) The main river bifurcated at a point upstream of nose of the central bela.

(*iv*) The right channel developed and the belas in this cha disappeared. The right face of the main bela eroded and the nose of spur A washed away.

(*v*) The creek close to the main bela which used to to Bay 4 became choked. The water entering the channel flowed along the left bank to the left ur sluices and then parallel to the weir to Bay 4.

(*vi*) There was considerable erosion of the left bank bet the new Palkhu Spur and the left protection bund.

Having made the above observations, the run was conti with the river discharges of 1938 and the channel again surve The survey showed :—

(*i*) By the end of June the right channel was over-devel and the point of bifurcation of the main stream moved to a place just downstream of spur G. H. Looking downstream from Spur B 4, the main cha flowed along the line of spurs to the right undersl Immediately upstream of the nose of the ce bela a small portion of the discharge entered the channel. The water in the left channel flowed small creek to the Palkhu Spur and then along th guide bank.

(*ii*) In flood, three-quarters of the discharge flowed the right channel and one-quarter down the left

(*iii*) As the river fell in September it became difficult t the supplies into the left channel for feeding the owing to the formation of belas in the left channel

The answer to the question can be summarised as follows :

A continuation of the present method of regulation will r in the over-development of the channel to the undersluices and the silting up of the channel to left undersluices. It will thus become difficult to the canal on a falling river.

2. *What should be done to obtain the greatest advantage of Bay 4* The object of the construction of Bay 4 was the development of left arm of the river and to pass the surplus discharge. It was desi to take 125,000 cusecs but owing to the development of the right of the river the channel to Bay 4 was deteriorated and it can be

pass half of the supply for which it was designed. Since the right channel takes the major portion of the dischargo in flood, the hays of the right channcl arc endangered.

The first step in an attempt to uso Bay 4 was made by connecting the bay hy a cut to the right channel.

A cut was made in tho main bela from a point opposite spur A to Bay 4. Tho cut was 60 feet wido, 12 feot deep and 2,200 feet long. An attempt was made to develop the cut with the winter freshets. The model was monlded to the river survey of 1938 and a discharge of 10,000 cusecs was run at first and was leter increased to 54,000 cusecs representing freshet discharges in January. The following pond levels were maintained :—

Right pond at R. L. 730.

Left pond at R. L. 729.

The central undersluices were opened as much as possible In a period equivalent to two days the cut widened to 150 feet. The next freshet discharges run were 39,000 cusecs and 76,000 cusecs with pond levels at R. Ls. 732 and 730·5 on the right and left respectively. As a result the cut developed to a bed width of 450·0 feet. This was increesed to 850 feet when the April discharges were run. The mode was also run during May, June, July and August.

At the beginning of June, it was noticed that the whole of the hela on the right side of the cut was washed away and only the bund which divided the weir into two portions remeined. The conditions of flow at this stage were interesting. There was a channel to Bay 8; a second to Bay 4 and a third on the left to the left undersluices. The hifurcation of the stream towards tho right and the central undersluices took place oppositc spur A. The action at the nose of the main bela was severe. By the middle of June the hund at Bay 5 was washed away thus connecting the two channels. It was noticed that ahout 80 per cent. of the supply passed through the right channel and the approach of the river from Bays 3 to 8 was practically straight in high flood discharges. When the river fell in Septemher it was found that no water passed down the left channel helow a discharge of 20,000 cusecs and the canal supply came from the right channel.

In the next test the model was run for a low discharge year. It was found that the cut developed fully during the June discharges and the final conditions were almost the same as those ohtained in tho previous test.

It has been shown from these tests that when the cut develops, the bund which divides the weir into two is washed away. The right edge of the main hela is eroded and the approach of the river to Bays 3 and 4 straightens out. Severe action develops at the nose of groyne 4. If tbe right edge of the hela is further eroded it is prohahle that in flood

the central current may take a course straight to Bay 1 or the left undersluices. The bed of the river in front of Bay 8 becomes slightly raised and discharges in the left channel drop almost to zero. In low river the canal is fed from the right causing parallel flow along the weir from Bay 6 to the left undersluices.

If this method is adopted on the prototype the groynes of Bay 4 shall have to be dismantled or strengthened.

The effect of dismantling the bund at Bay No. 5 connecting Bay 4 to the right channel and constructing a bund to the bela from Bay 3 has been examined.

As the central bela had extended to the groynes of Bays Nos. 4 and 5, a cut 50 feet wide was made between Bay 4 and the bela. A discharge of 25,000 cusecs was run and the canal was opened. The following pond levels were maintained :—

Right R. L.	732·5
Central R. L.	731·0
Left R. L.	731·5

The whole of the discharge in the right arm was passed through Bay 4 and the originally narrow passage widened to 260 feet. Parallel flow started from groyne 6 to Bay 1. At groyne 4 the action was severe. Smooth flow took place along the bela, no erosion taking place with a discharge of 25,000 cusecs. The portion of the bela in front of Bay 5 was attacked and consequently the passage widened as the discharge increased. On the left side, Bays Nos. 1 to 3 showed signs of silting up. Downstream of the nose of the central bela the left stream divided into two branches one along the Palkhu spur and the guide bank and the other along the left guide bank which entered the regulator. The other flowed along the bela to Bay No. 1 curving along the upstream divide wall.

A discharge of 76,000 cusecs was now run. After half an hour a portion of the bund from the bela to groyne 3 gave way. The discharge was then increased to 100,000 cusecs. The shutters in Bays 6, 2 and 1 were dropped to pass the surplus over that taken by the central undersluices. The tail end of the bela was not eroded with this discharge. There was, however, some erosion of the right edge of the bela in front of spur A. Parallel flow still persisted from Bay 7 to Bay 4. One important change brought about with this increased discharge was that the channel first approached Bay 6 and then took a course to Bay 4.

The discharge was next raised to 150,000 cusecs and this broke the bund. The path of flow was, however, similar to that observed

with 100,000 cusecs discharge. The distribution of discharges for the two halves of the weir was as follows :—

	Cusecs.
Right	89,000
Left	40,000

Swirls of appreciable magnitude formed at groyne 5.

In order to study the distribution of supply during high floods, discharges of 264,000 cusecs and 400,000 cusecs were run. The bela was over-topped in the case of 264,000 cusecs, the water spilling over from right to left. Bay 4 under these conditions did not pass the designed discharge due to bad curvature of flow. With a discharge of 400,000 cusecs the whole of the bela as well as the bund was over-topped and the flow was more or less evenly distributed.

The result of the test shows that running the model for a period equivalent to one year, the section of the river in front of Bays 5 and 6 does not widen materially. Flow to Bay 4 still takes place along a course parallel to the weir from Bay No. 7. Before reaching Bay 4 it strikes against the bund and this bund may fail as the velocity of the water against it in ordinary discharges is from 8 to 10 feet per second. In low discharges the tail of the bela may extend towards the weir Bays 4, 5 and 6. On the left side Bays 1 to 3, unless they are worked frequently, are bound to silt up.

Connecting Bay 4 to the right channel does not lead to a great improvement. Due to a bad approach to Bay 4 ; this Bay does not take its full share of the discharge.

The idea of Mr. Nicholson in constructing Bay 4 was to obtain curvature of flow above the undersluices so that the silt would tend to pass to Bay 4 and the cleaner surface water to the Head Regulator of the canal. Owing to the growth of the bela in front of Bay 4 due to the alterations in the system of regulation the object of Bay 4 could not be achieved. In an attempt to develop the channel to Bay 4, it was decided to investigate the effect of spurs on the left bank. A 'T'-headed spur 500 feet in length was constructed in the position of the Old Palkhu spur. The bed was moulded to the 1938 survey and the discharges of 1937 were run. It was found that there was a tendency for the channel to Bay 4 to develop with this spur. Spurs of different lengths and in different positions were then tried and an improvement took place with a spur 700 feet long and situated 100 feet upstream of the Old Palkhu spur.

A second spur was now constructed in the position shown in Fig. 57. The second spur improved conditions considerably and the channel to Bay 4 developed, some of the belas being washed away.

While investigating the effect of spurs, the silt entering the canal in each of the cases was also determined. For each test the model

was laid out according to the 1938 surveys and a discharge of 85,000 cusecs was run for a period of 6 hours. The silt entering the canal during this period was trapped and measured. The results are given in Table 26. It will be seen that the construction of one spur reduces the silt entry to one-half and the construction of a second spur reduces it a further 10 per cent.

From these experiments it will be seen that the maximum advantage of Bay 4 can be obtained by two methods. The first method is to make a leading cut in the main bela from the right to left. By this means, the approach to the bay is made direct and the bay receives its designed discharge. The objection to this method is the reverse action that takes place upstream of the weir.

The alternative method is to combine two spurs in the left bank in such a position that the main current is forced to develop the channel to Bay 4. This method has the added advantage of reducing considerably the silt entry into the canal.

The remaining items of the investigation are still being studied.

Experiments in the remodelling of Dhanaura Regulator.—Considerable silt trouble has been experienced in certain branches of the Western Jumna Canal. In order to minimise these it was decided to stablise the reach ofc anal above Dhanaura Regulator by raising the Full Supply Level and thus flattening the slope. Information was required on the levels upstream and downstream, the protection required downstream and the design to be adopted in remodelling the regulator.

A section of the existing work is given in Fig. 58 and the alterations proposed are also shown. A model of the existing structure was examined. A discharge of 6,200 cusecs was run with upstream and downstream water levels corresponding to R. L. 853·27 and 853·14 respectively. The results are plotted in Fig. 59.

The crest was then raised in three stages :—

Stage No. 1	R. L. 848·52
Stage No. 2	R. L. 849·91
Stage No. 3	R. L. 850·91

The first and the third stages of the raised crest were examined for the following conditions of flow while the second stage was examined for full supply only.

(1) Full supply	.. ..	62,000 cusecs.
(2) (*a*) Low Supply	.. ..	5,000 cusecs.
(*b*) Ditto	.. ..	3 retrogression.
(3) (*a*) Low Supply	.. ..	4,000 cusecs.
(*b*) Ditto	.. ..	3 retrogression.

The proposed design for the first stage is shown in Fig. 60. The model was run in each case for a period of 4 hours. The observations were taken for all the different conditions of flow. The results obtained are given below. The downstream water levels were maintained the same as given by the Superintending Engineer.

FIRST STAGE.

Discharge.	Downstream water level maintained.	Upstream Experi-mentally determined level	Water level calculated by S. E.	Calculated "C" by S. E. 2.8. "C" experimentally determined.	Condition of flow at the D. S. end.	Illustrated in Fig. No.	Scour.
Full Supply 62,000 cusecs	R. L. 853·14	854·63	854·27	2·65	A big back roller formed	a	Nil
Low Supply 5,000 cusecs.	R. L. 852·44	853.79 gate could not be used as its use gave a minimum level of 855.10.	854·27 with gate.	2·62	Ditto	b	Nil
Low Supply 5,000 cusecs.	R. L. 849·44	Ditto	Ditto	2·84	No back roller.	c	0·5′
Low Supply 4,000 cusecs	R. L. 851·94	Gated pond 854·27 gate opening 2·68′.	854·27	..	Ditto	d	Nil
Low Supply 4,000 cusecs.	R. L. 848·94		3·45′	..	Ditto	e	Nil

In all the above cases the value of C obtained from the experiments was lower than that obtained by the office calculations.

SECOND STAGE.

In the second stage the crest was raised to R. L. 849·91. The bed of the cistern was at the same R. L. as that in the first stage. The full supply discharge of 6,200 cusecs was tested. A large back roller was formed while no scour took place. The calculated and the experimentally determined upstream water levels and the co-efficients of discharge are as follows :—

	Calculated.	*Experimentally determined.*
Upstream Water Level	R. L. 855·27	R. L. 855·80
Co-efficient of Discharge	2·80	2·78

THIRD STAGE.

In the third stage the crest was raised to R. L. 850·91. All other conditions of experiment were the same as in the first two stages. All the discharges were examined, the results obtained are given in the table below and shown in Fig. 61.

D. S Level.	Discharge in cusecs.	Upstream water level — Experimentally determined	Upstream water level — Calculated by S. E.	'C' Calculated 2·8 Experimentally determined.	Condition of flow at D. S. end.	Scour.	Illustrated in Fig. No.
853·14	Fully Supply 6,200.	856·85	R. L. 856·27	2·72	A large back roller formed	Nil	a
852·44	5,000 cusecs	856·25 non-gated	856·27 gated.	2·62	Ditto	Nil	b
849·44	5,000 cusecs	856·13 non-gated.	Ditto	2·69	Back roller absent.	·56′	c
851·94	4,000 cusecs	856·27	856·27	..	Ditto	Nil	d
848·94	4,000 cusecs	856·27	..	..	Ditto	Nil	e

Improvements effected in the proposed design.

(a) *Shape of the Cistern.*—In the original design the bed of the cistern was joined to the downstream floor by a glacis with a slope of 1 in 8. As a result of the model tests it was shown that the vertical drop was much more effective than the sloping glacis in reducing the action downstream and in throwing the high velocity jet to the water surface. In all later models this design of cistern was adopted.

(b) *Slope of upstream edge of crest.*—From the tables it will be seen that the value of the co-efficient of discharge determined experimentally was considerably lower than the calculated value. In order to increase the value of the co-efficient, experiments were carried out on the effect of the shape of the upstream edge of the crest. It is found that if the upstream edge of the crest was an arc 2·4 feet in radius, then the co-efficient increased from 2·6 to 2·9 in the case of a discharge of 5,000 cusecs in the experiment in the third stage. A curved edge as above was recommended.

(c) *Downstream edge of crest.*—In the proposed design, the crest extended from a distance of 2 feet downstream of the gate line. This projection appeared to reduce the effect of the cistern. Experiments showed that when the crest finished at the gate line, the cistern was more effective in dissipating energy. This suggestion was incorporated in the design. The final design is shown in Fig. 62.

Investigation of a model of Jaba Level Crossing, Upper Jhelum Canal.—The Jaba Level Crossing conveys torrent water across the canal. The crossing was constructed in 1911 and was of a total length of 91 feet. Due to retrogression, the length of the floor has been increased a number of times and now the total length is 394 feet. Retrogression is still in progress and further damage occurred in 1938. An investigation was started to determine the most suitable method of checking the retrogression and stablising the structure.

A model of the existing structure was made to a scale of 1/40 and tested for the following conditions :—

(a) Total discharge of 56,000 cusecs, corresponding to a discharge of 93·3 cusecs per foot run, with upstream water R. L. 809·05 and downstream water R. L. 790·11.

(b) Total discharge 16,209 cusecs, corresponding to a discharge of 27·0 cusecs per foot run, with upstream water level R. L. 806.55 and downstream water level R. L. 795·70.

(c) Total discharge 12,091 cusecs, corresponding to a discharge of 20·1 cusecs per foot run, with upstream water R. L. 806·55 and downstream water R. L. 795·70.

The following observations were made for each of the above conditions of flow :—

(i) Water surface profile.

(ii) Depth of scour and general retrogression.

(iii) Velocity determinations.

It is found that with discharges of 27·0 and 20·1 cusecs per foot run little action took place. With a discharge of 93·5 cusecs per foot run there was considerable action. The results for the test are shown in Fig. 63. It will be seen that no standing wave formed on the pucca work. Hurdling took place in the sand bed below the work and produced a deep scour hole.

The model was now altered according to the design shown in Fig. 64. Below the 'C' line of wells the glacis was given a slope of 1 in 4 to the downstream R. L. 778. A horizontal floor 44 feet in length was then added. The model was examined for a discharge of 93·3 cusecs per foot run and it was found that a deep scour hole, equivalent to 21 feet, was formed. The effects of a baffle wall and staggered blocks was determined. While these reduced the scour the action was still heavy.

The horizontal floor was now extended by 38 feet and the effect of a baffle wall and staggered blocks again examined. This showed some improvement.

The R. L. of the floor was now lowered from 778 to 776 and the experiments repeated. This test showed that the standing wave now formed at the toe of the 1 in 4 glacis and that the scour had been reduced to about 5·8 feet. It was recommended, therefore, that the floor should be lowered to R. L. 776 and connected to the existing work by a glacis with a slope of 1 in 4. The length of the horizontal floor should be 80 feet and it should be protected by a system of staggered blocks. Such reconstruction would render the work safe for the present.

The question of checking further retrogression is now to be examined. A model of a length of the Lower Jhelum Canal, the Level Crossing and the Jaba Nullah has been constructed to a scale of 1/20. Work on this model is now in progress.

Design of falls on the Pakpattan Link, Haveli Project.—Three falls of between 6 to 7 feet were to be constructed in the Pakpattan Link which had a maximum discharge of 700 cusecs. This gave an opportunity of testing out designs in the laboratory and comparing the results with those obtained in the field under similar conditions. The designs for the falls were prepared by Mr. Kanwar Sain of the Central Designs Office, by Mr. Montagu and by Mr. Inglis. Models of the falls were constructed and examined for similar discharge conditions. The designs of the falls are shown in Figs. 65, 66 and 67. The observations made in order to compare the falls were bed scour, side erosion and the co-efficient of discharge. The following table shows the figures obtained :—

	Montagu Fall.	*Inglis Fall.*	*Central Designs Fall.*
Bed Scour.. ..	4·47′	Nil	1·74′
Side erosion ..	4·93′	Nil	2·26′
Co-efficient of discharge	2·90′	3·00	2·90′

In the experiments the Inglis fall was fitted with a baffle and deflector wall recommended by him. The Montagu fall and the Central Designs fall had plain floors. In a further test both the Montagu fall and the Central Designs fall were fitted with staggered blocks. The results of the test are given below :—

	Montagu Fall.	*Central Designs Fall.*
Bed Scour	1·07′	Silt deposited to a depth of 0·76′.
Side erosion	Nil	Nil

The final comparison from the laboratory experiments shows that the Inglis fall gives a higher co-efficient of discharge than the others. With the addition of staggered blocks, the Central Designs fall gives similar results to the Inglis fall so far as bed scour and side erosion are concerned.

Falls to the three designs have been constructed but at the time of writing no results of their behaviour are available. These will be reported later.

A Rapid Method for determining the Uplift Pressures on models of Weirs.—A method for demonstrating the flow under models of weirs by using a small capillary tank was described in the Annual Report for 1938. During the present year the method has been developed so that it is now possible to measure the pressures. A photograph of the apparatus is shown in Fig. 68.

Small holes were drilled through the brass plate forming the back of the capillary tank and to these brass nipples were fitted. The nipples were connected by rubber tubing to a circular brass chamber 1½ inch in diameter and 1 inch in depth. Twelve holes were drilled in the circumference of the chamber and one in the centre of the upper surface. Brass nipples were soldered in the holes and connected to the rubber tubes. Each nipple of the chamber was fitted with a stop-cock so as to close the connection between the chamber and tank when desired.

The central nipple of the chamber was connected to a micro-manometer so that considerable accuracy in reading the pressures was obtained.

In order to use the apparatus, the pressure transmission chamber is filled with water, special care being taken to remove air bubbles. Air bubbles are also removed from the connecting tubes. The pressure transmission chamber is then connected by the series of tubes to the nipples in the capillary tank. A celluloid model of the work to be tested is then inserted in the capillary tank and the upstream and downstream levels adjusted. When the levels have become constant each point of the capillary tank is connected to the pressure transmission chamber in turn by opening the appropriate stop-cock. The pressure is transmitted from the chamber to the manometer and observed. After observing the pressure at one point the stop cock is closed and each of the others opened in turn.

The results obtained by this method have been exhaustively checked with those obtained by the electrical and hydraulic methods. A set of plottings of the results by the different methods is given in Fig. 69.

Silt Survey of the Lower Chenab Canal.—A silt survey of the canal has been commenced on the Main Line and all branches with the object of determining the effects on the canal of the silt excluder at Khanki Headworks. The observations during the year are outlined in Table 26, together with remarks as to their ultimate utility.

TABLE 26.

Observations.	Frequency.		Ultimate Utility.
	In time	In distance.	
(1) Sampling of bed silt from *centre of channel and its* analysis	Half-yearly..	Every mile *of channel.*	The grade of bed silt is useful in *fixing the optimum* slope of the bed
(2) Levels of water surface are read from gauges	Monthly ..	Ditto ..	As a sensitive index of the movement of bed silt
(3) Levels of silted bed obtained by soundings.	Half-yearly.	Ditto ..	For estimation of amount of sil and scour at each point.
(4) Surface widths and depths ..	Ditto ..	Ditto ..	To watch changes in the quanti ties with changes in the sil grade and for calculating wette perimeter.
(5) Samples of silt below off-takes	Ditto .	Below head of offtake	To study the distribution of si between parent and offtake
(6) Directions of flow of water at bifurcations	At Sagar Buchisna and Nannana.	..	To study the distribution of silt a bifurcations

Observations 1—5 have been carried out mostly in Octobe 1938 and the results of (1) were plotted as longitudinal sections. Thes showed a general reduction in silt particle size as one proceeds dow the canal. The question whether the reduction in size is due to th attrition of coarse particles or whether the present observation give only a temporary picture of a silt wave running down the cana will be settled by comparing the yearly observations in future. It is indicated by the gradual change in silt grade, however, that a mile is an adequate interval for these observations. In the next report it is hoped to give some account of the variations that occur in a channel during a year.

Silt Survey of the Upper Bari Doab Canal.—The entry of shingle and silt into the Upper Bari Doab Canal has been the cause of considerable trouble for a number of years. In certain reaches of the Main Line, the bed is now five feet above designed bed level. Considerable expenditure has been incurred in pitching the sides of the Main Line and Main Branch Upper with boulders. The trouble has now extended to the smaller branches and distributaries. Silt investigations have been in progress for a number of years with the object of obtaining data upon which recommendations for silt control might be based. During the year the results of these investigations have been reviewed.

The bed of the river at the Headworks at Madhopur is composed of boulders. The approach of the river to the Headworks varies and in consequence alterations take place in the distribution of the silt in the head regulator bays. The river surveys and current directions for 1937 and 1938 are shown in Fig. 70. In 1937 the river approached the head regulator from the right bank while in 1938 the river flowed along the left marginal bund. The river conditions in May 1938 were exceptional as the discharge reached 34,000 cusecs, an abnormally high figure for this month. Under these conditions the canal is usually closed, but in 1938 closure was impossible. In spite of this, shingle did not enter the canal as in previous years when the river approach was from the right.

The shingle entering into the canal for similar discharges in 1936 and 1938 is given in Table 27. No qualititive estimation of the amount of shingle is possible but its presence or absence is recorded by the sampler. In 1936 shingle was entering all bays of the regulator with the exception of bay 12. In 1938 the only bay in which it was present was No. 7. During 1938 the height of the shingle ramp in front of the head regulator was also controlled by scouring closures. The alteration in the approach of the river and the control of the height of the shingle ramp are probably the main factors accounting for the smaller quantity of shingle entering the Canal.

The pocket was surveyed in September 1938 in order that conditions might be compared with those of 1937. The results of the survey are shown in Fig. 71. It will be seen that the ramp in 1938 is generally 2 feet lower than in 1937 and that the channel of approach is different.

For some years the quantity of silt entering each bay of the head regulator has been determined. The results for 1936, 1937 and 1938 are given in Table 28. This table is divided into three parts which shows silt entery for river discharges up to 17,000 cusecs, between 18,000 cusecs and 27,000 cusecs and above 27,000 cusecs. For river discharges up to 17,000 cusecs in the river, the right divide, bays 1 to 6, take the major portion of the silt in all years. For river discharges between 17,000 cusecs and 27,000 cusecs in 1936 and 1937,

the right divide also took much more silt than the left divide. 1938, however, the left divide takes more silt than the right for discharges. In 1937 for river discharges above 27,000 cusecs silt entering the bays of the right divide was much greater than entering the bays of the left divide. In 1938 for the higher discharges the amount of silt entering the bays of the two di appears to be approximately the same.

The object of studying the distribution of silt through the regulator has been to obtain data for the design of a silt ejector situated at the downstream end of the divide. An account o model experiments in this connection was given in the Annual R for 1935. Even with the alteration of the distribution of silt a the head regulator, there appears to be no reason to suppose tha silt ejector as designed will not work efficiently.

The silt ejector in the Salampur has continued to work effici In order to measure the amount of silt ejected, the water passing thr the ejector was led into a silting tank and the deposit measured a run of 24 hour period. A comparison of the results obtained in 1938 those of 1936 and 1937 is given in Table 29. The results are sl as shingle and silt above ·2 mm. in diameter passing the ejecto cusec day. The quantity of shingle passing the ejector is app mately the same in 1937 as in 1936. The amount passing in 19 considerably less than in 1937. This must be attributed to the sm quantity which entered the head in 1938 as was shown by samp With the present river conditions, therefore, there should be no da in passing the combined silt loads of the two divides through Salampur feeder ejector, since it has been shown that it can c much larger quantities of shingle than it did in 1938. Much la quantities of silt have also been passed through the ejector tha 1938. For the silt grade also the ejector appears to have the ne sary capacity.

The reduction of the silt load will undoubtedly affect regime of a channel. If the ejection of silt is carried out it will bec necessary to stabilise reaches of the canal with reference to its grade otherwise a silt coarser in grade than already present on the may be transported to lower reaches which will involve considera expenditure in maintenance. In order to obtain some informat regarding the effect of silt exclusion, water surface slopes have b observed on the Salampur feeder since 1933, the date of the beginn of silt ejection. The results of the series of years have been examin The water surface slopes between falls have been flattening and t are still continuing to flatten in 1938. The process of attaini regime is, therefore, slow and will give ample time after silt exclusi commences to consider proposals for stabilisation. It is hoped t the silt ejector on the Main Line will be constructed during 1939-4 when intensive observations on its working will become available.

Model of Khanki Weir at Malikpur.

SILT ENTRY IN THE CANAL WITH THE DIFFERENT METHODS OF FEEDING THE CANAL.

CANAL SUPPLY 10,000 CUSECS.

Description of the run.	Discharge in the right arm.	Discharge in the left arm.	Left pond level.	Gate openings.	Centre pond level.	Gate openings.	Right pond level.	Gate openings.	Silt in cubic feet in the canal.	Proportion of silt in the two arms.
										L : R
Without any spur	20,832	45,144 cusecs.	732·0	6' 1st gate.	731·5	7·5' all gates.	732·5	4·2' all gates.	·30	1 : 1·9
With one spur at Palkhu arm ..	20,832	45,144 cusecs.	732·0	6' 1st gate.		7·5' all gates.	732·5	4·2' all gates.	·28	1 : 1·3
With two spurs in the left arm..	20,832	45,144 cusecs.	732·0	6' 1st gate.		7·5' all gates.	732·5	4·2' all gates.	·20	1 : ·9

TABLE 27.

Date	11-8-36.	29.5-38	
Discharge of river in cusecs.	25,120	24,957	
Bays of the head regulator—			
1	P	O	P=Shingle entering the regulator bay.
2	P	O	
3	P	O	O=Shingle not entering the regulator bay.
4	P	O	
5	P	O	
6	P	O	
7	P	P	
8	P	O	
9	P	O	
10	P	O	
11	P	O	
12	O	O	

TABLE 28.

Table comparing the silt concentration in the bays of head regulator in 1936-37 and 1938.

YEAR.	1936.				1937.					1938.				
River Discharge.	PARTICLES ABOVE .2 MM IN DIAMETER AS OZ. P. C. F. OF WATER.				River Discharge.	PARTICLES ABOVE .2 MM IN DIAMETER AS OZ. P. C. F. OF WATER.				River Discharge.	PARTICLES ABOVE .2 MM IN DIAMETER AS OZ. P. C. F. OF WATER.			
	Bays 1—3.	4—6.	7—9.	10—12.		1—3.	4—6.	7—9.	10—12.		1—3.	4—6.	7—9.	10—12.
					17,072	·806	·241	·117	·076	16,681	·037	·045	·030	·023
					17,534	1·028	·319	·088	·026	17,520	·104	·088	·172	·181
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	17,936	1·540	·029	·082	·085					
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	18,450	·798	·289	·042	·018	18,444	·138	·232	·295	·178
					18,920	·796	·726	·249	·130					
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	19,458	·566	·167	·120	·212	19,360	·142	·110	·302	·185
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	20,958	·726	·491	·123	·160	20,275	·048	·053	·107	·102
					22,920	·453	·152	·133	·118	26,488	·210	·326	·393	·135
										27,025	·051	·127	·142	·105
					22,458	1·654	·350	·095	·072	31,856	·150	·535	·407	·127
					22,520	·633	·318	·272	·230	34,760	·488	·841	·388	·239

TABLE 29.

Table comparing the silt and shingle ejected by silt ejector in the Salampur Feeder.

Date.	Silt above .2 mm diameter ejected per cusec day.	Shingle ejected per cusec day in cft.	Date.	Silt above 2 mm diameter ejected per cusec day in cft.	Shingle ejected per cusec day in cft.	Date	Silt above .2 mm diameter ejected per cusec day in cft.	Shingle ejected per cusec day in cft.
27th May, 1936 ..	57·80 C. F.	4·04	20th May, 1937 .	86·90	4·3	24th May, 1938 .	107·68	1·36
30th June, 1936 ..	52·10	5·47	10th July, 1937 ..	75·3	4 ·	26th June, 1938 ..	28·60	·81
31st July, 1936 .	49·20	1 62	10th August, 1937..	92 2	4·6	25th July, 1938 ..	51·78	1·45

FIG. 45

PANJNAD RIVER D/S 1938 (CURRENT DIRECTIC

DATED 1738

SCALE 4" = 1 MILE

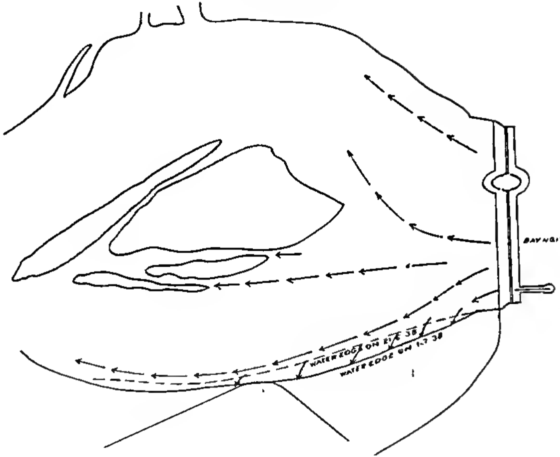


Fig. 45-A.

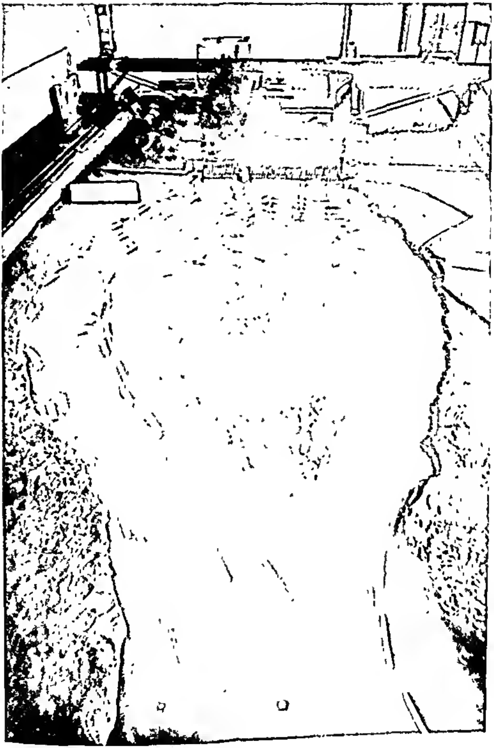


Fig. 46.

EXTENSION OF THE LEFT GUIDE BANK.

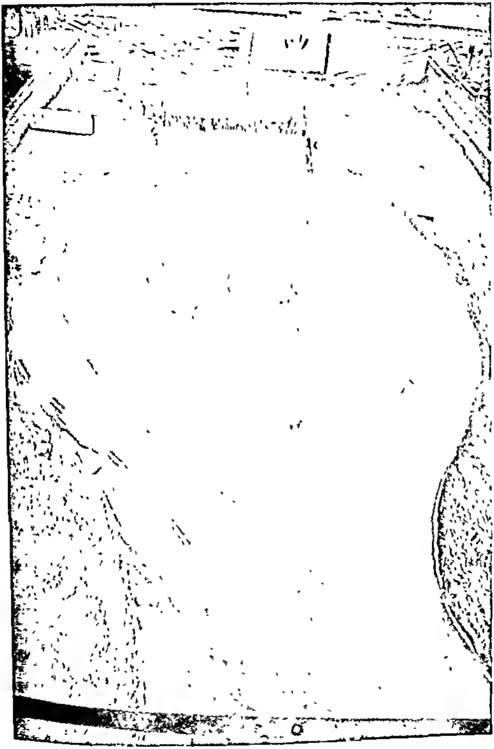


Fig. 46.

EXTENSION OF THE LEFT GUIDE BANK.

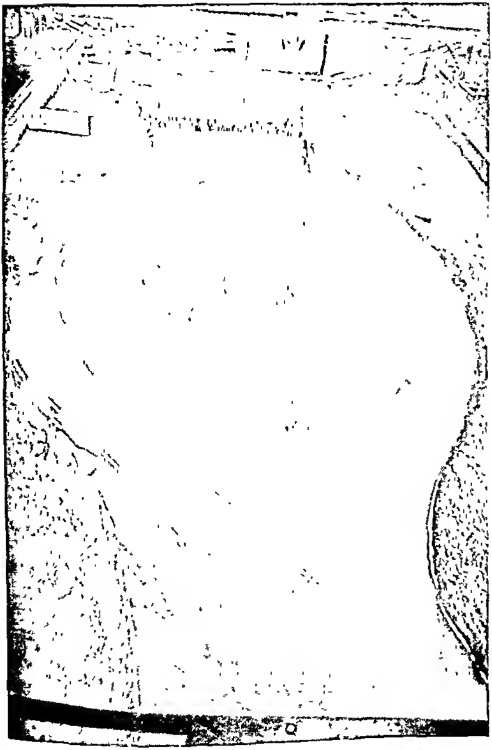
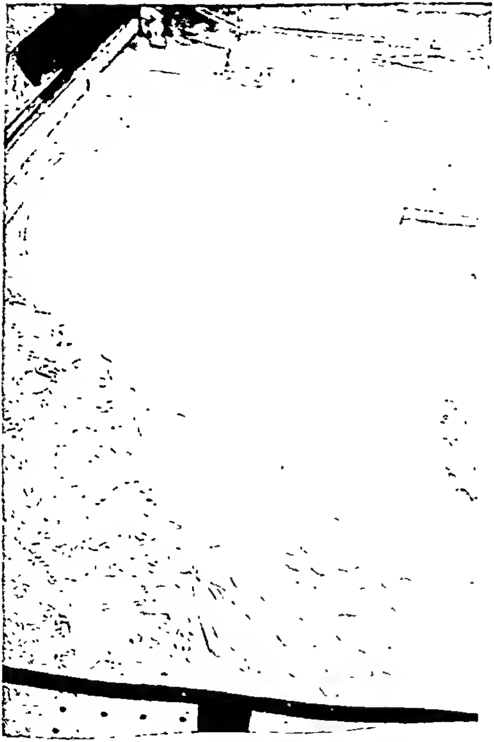


Fig. 47.

EFFECT OF A SINGLE SPUR IN THE LEFT CHANNEL.



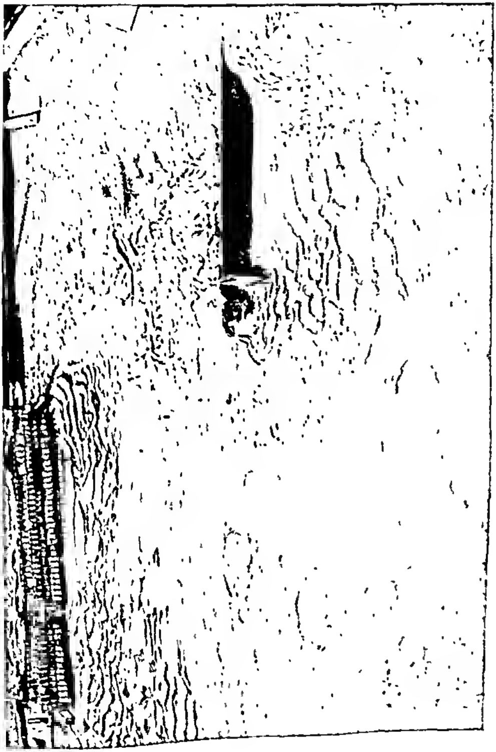


Fig. 49.

EFFECT OF TWO SPURS IN THE LEFT CHANNEL.

Fig. 49.

EFFECT OF TWO SPURS IN THE LEFT CHANNEL.

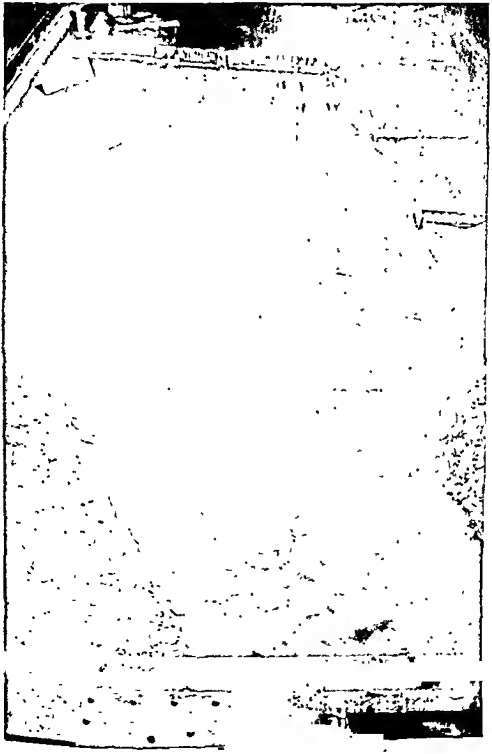
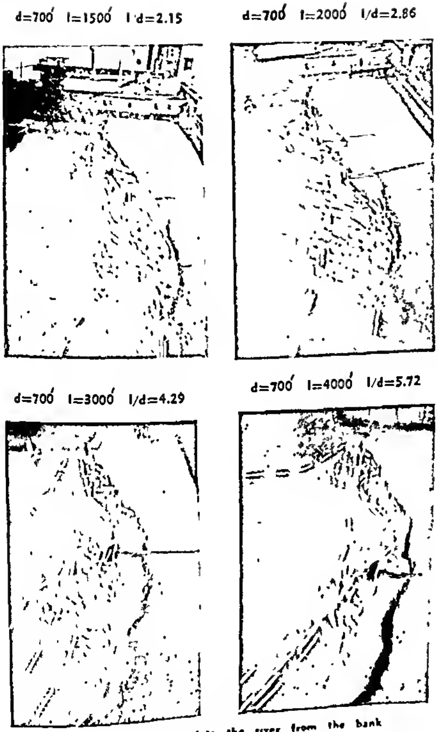
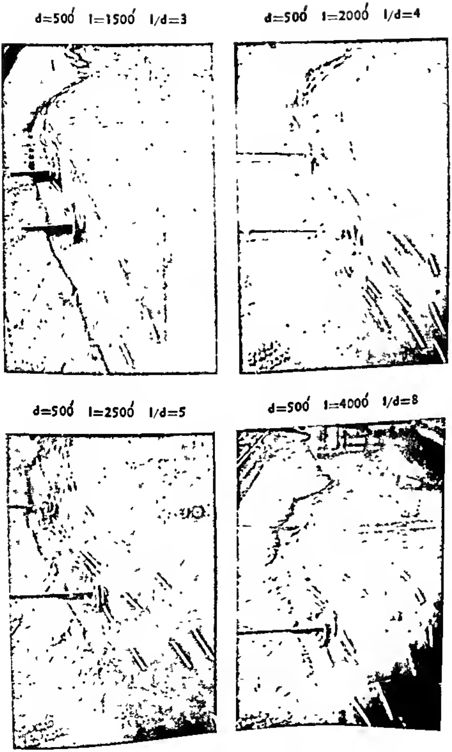


Fig. 50.



Where d=distance into the river from the bank
l=distance between the spurs

Fig. 51.



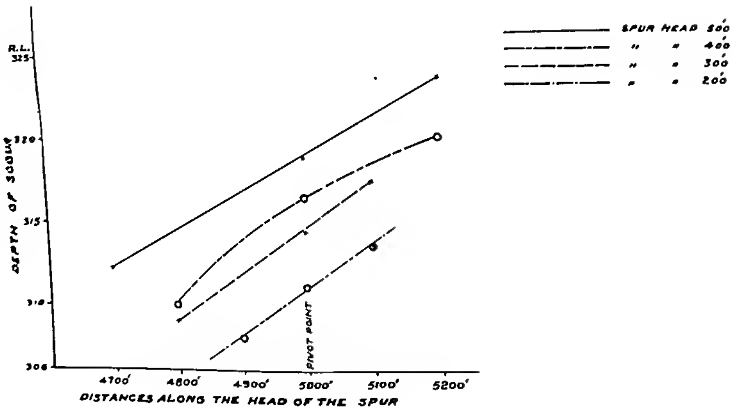

SPUR HEAD 500'
" " 400'
" " 300'
" " 200'
R.L. 325
320
315
310
306
DEPTH OF SCOUR
PIVOT POINT
4700'
4800'
4900'
5000'
5100'
5200'
DISTANCES ALONG THE HEAD OF THE SPUR

FIG. 53

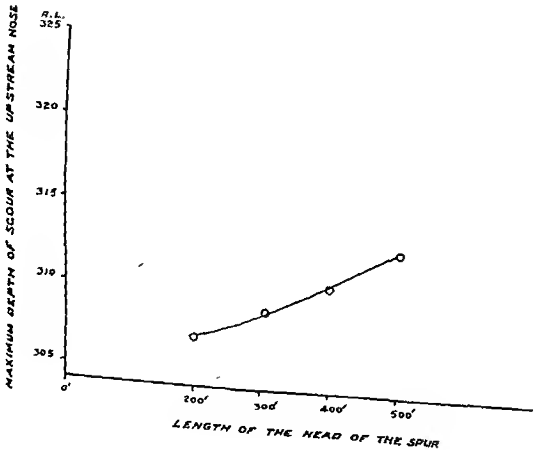

R.L.
325
320
315
310
305
0'
200'
300'
400'
500'
MAXIMUM DEPTH OF SCOUR AT THE UPSTREAM NOSE
LENGTH OF THE HEAD OF THE SPUR

FIG. 54

PANJNAD WEIR

SHOWING POSITION OF SPURS

HEAD OF SPUR = 200

a = 700'

b = 2000'

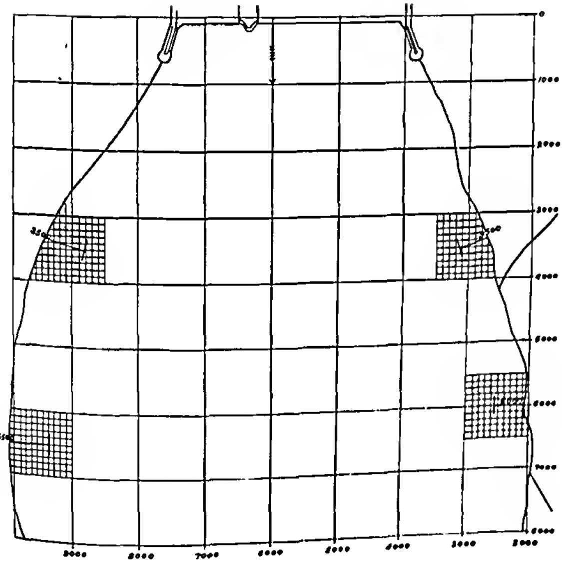


FIG. 55

KHANKI HEADWORKS

SCALE 1 IN = 2 MILES APPROX

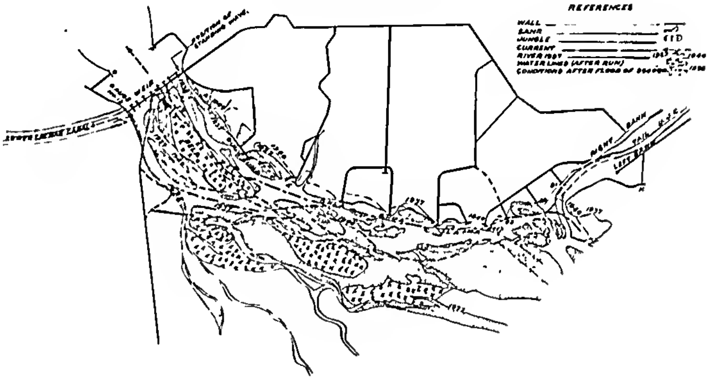


Fig. 56.

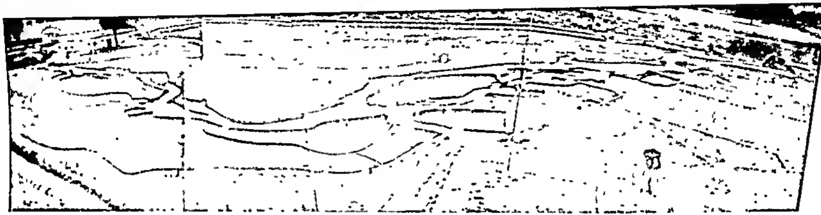


Fig. 57.

EFFECT OF TWO SPURS.

TOGRAPH SHOWING WATER BEING DEFLECTED TOWARDS BAY 4.

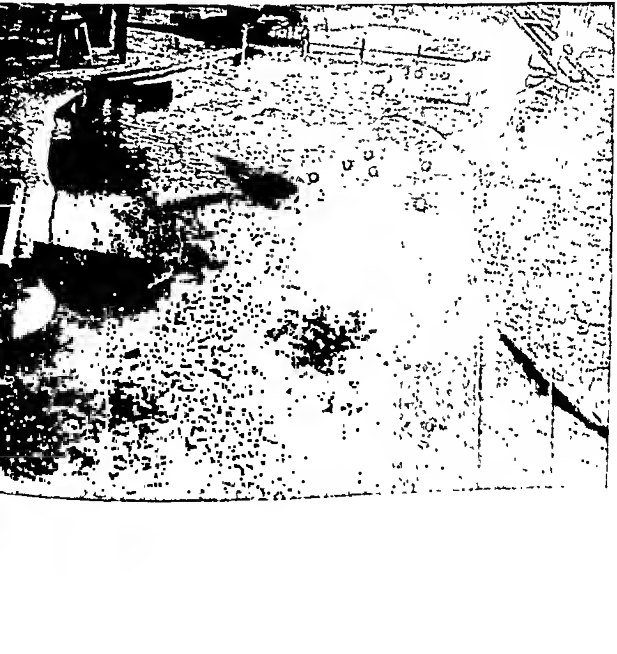


FIG. 58

KARNAL DIVISION W. J CANAL

DHANAURA REGULATOR R D. 1.49,500 M.L.L.

SHOWING PROPOSALS FOR REMODELLING

SCALE - 1/50

SECTION THROUGH REGULATOR

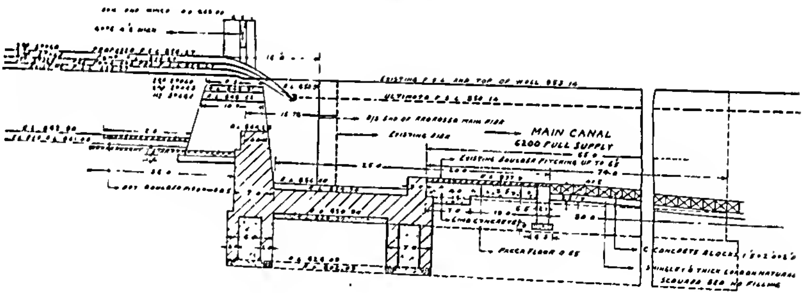


FIG. 59

DHANAURA REGULATOR

DISCHRGE 6200 CUSECS

MODEL OF WORK AS IT EXISTS

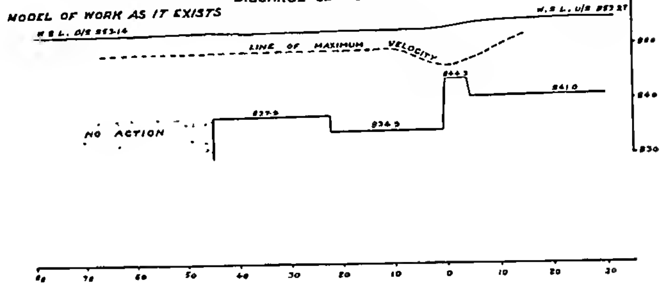


FIG. 60

DHANAURA REGULATOR
1ST STAGE
DISCHARGE 6200 CUSECS
(C = 2.645)

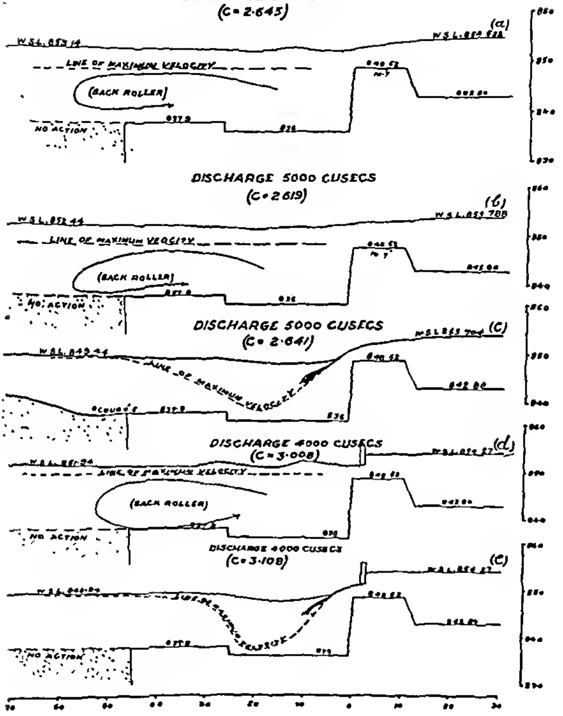


FIG. 61

DHANAURA REGULATOR

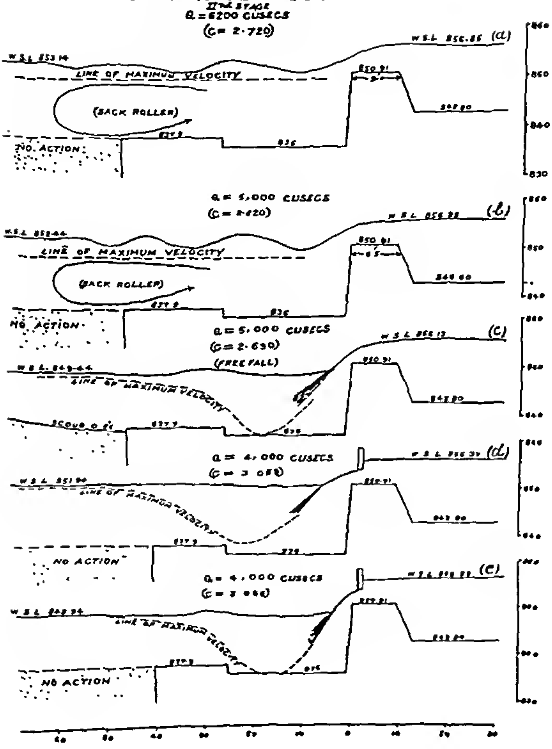
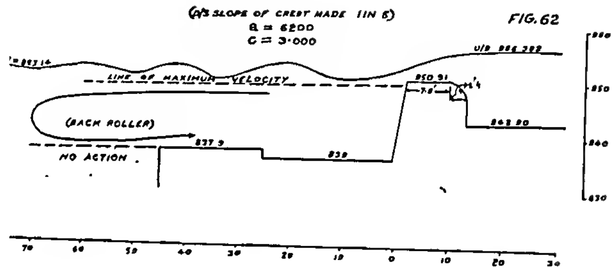


FIG. 62



(D/S SLOPE OF CREST MADE 1 IN 6)
Q = 6200
C = 3·000
U/S 856.282
850.91
LINE OF MAXIMUM VELOCITY
(BACK ROLLER)
837.9
838
849.20
NO ACTION
860
850
840
830
70
60
50
40
30
20
10
0
10
20
30

FIG.64

JABA LEVEL CROSSING

PROPOSED DESIGN

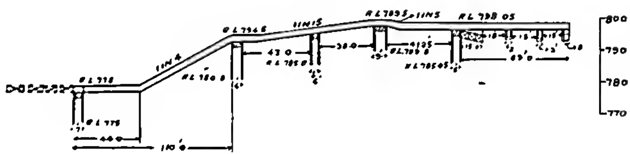


FIG 65

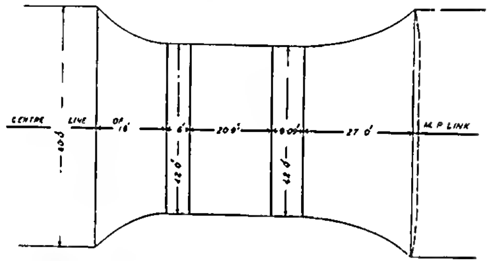
HAVELI PROJECT

MONTGOMERY PAKPATTAN LINK

DESIGN OF FALL AT R.D. 35500

BY Mr. A.M.R. MONTAGU

PLAN



SECTION

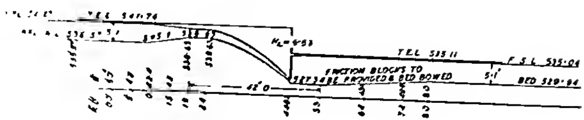


FIG. 66

HAVELI PROJECT
MONTGOMERY PAKPATTAN LINK
DESIGN OF FALL AT R.D. 37500
BY Mr. INGLIS

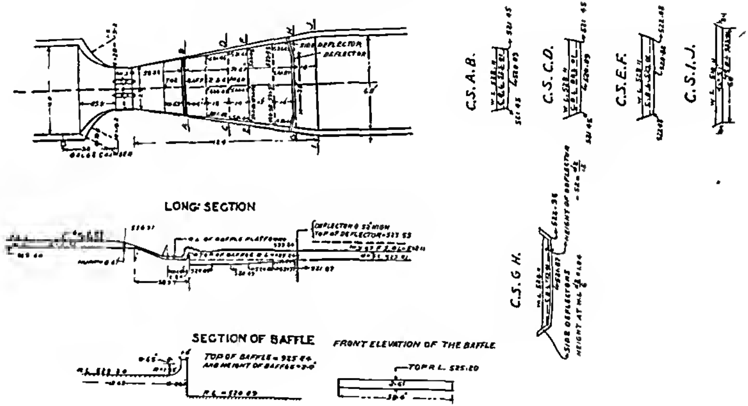


FIG. 67
HAVELI PROJECT
MONTGOMERY PAKPATTAN LINK
DESIGN OF FALL AT R.D. 40204
BY C.D.O.

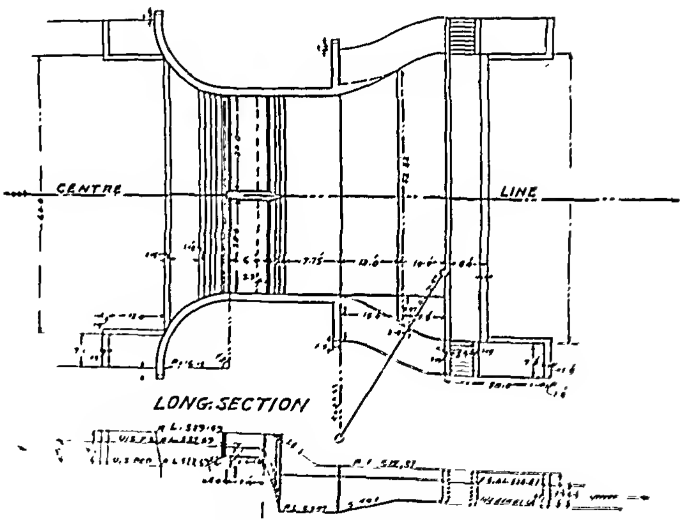
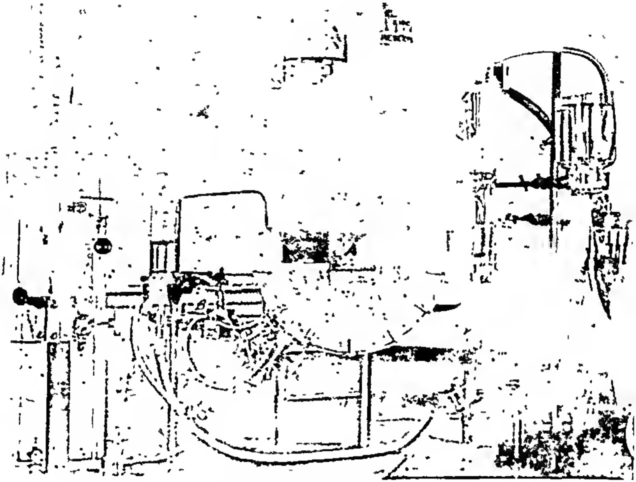


Fig. 68.

THE NEW APPARATUS FOR DETERMINING PRESSURE UNDER MODELS OF WORKS.



A—MODEL OF WORK

B—PRESSURE CHAMBER

FIG-69

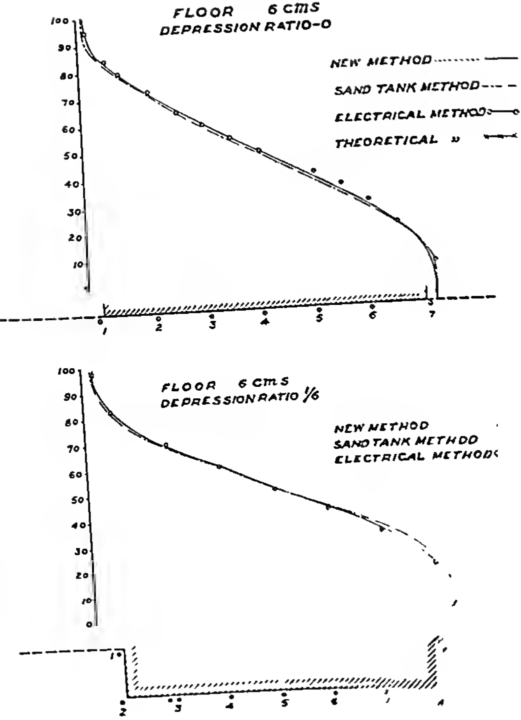

FLOOR 6 cms
DEPRESSION RATIO-0
NEW METHOD
SAND TANK METHOD
ELECTRICAL METHOD
THEORETICAL "
100
90
80
70
60
50
40
30
20
10
1
2
3
4
5
6
7
FLOOR 6 cms
DEPRESSION RATIO 1/6
NEW METHOD
SAND TANK METHOD
ELECTRICAL METHOD
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6

FIG. 70

PLAN
OF
RAVI RIVER U.S. MADHOPUR WEIR
SCALE = 1/2000

MADHOPUR DIVISION

POCKET SILT SOUNDING DIAGRAM

SCALE = 1/500

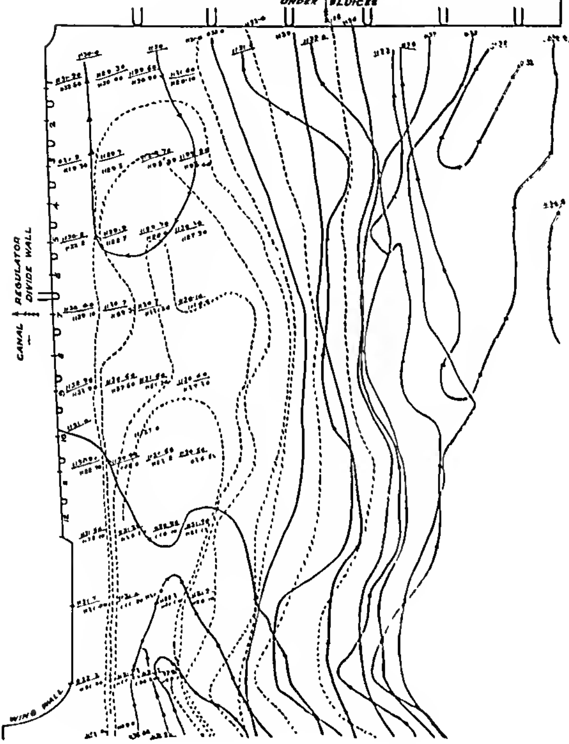
DISCHARGE = 14000 C.S.

FIG. 71

REFERENCES

LEVELS OF 1938

LEVELS OF 1937



LAND RECLAMATION SECTION.

The Movement of Salts in the Soil Profile with reference to the Formation and the Reclamation of Thur.—In the report for the year 1938 the factors causing the rise of the water-table and those responsible for the rise of salts to the surface were discussed. It was indicated that a characteristic Punjab alluvium consists of a soil crust of varying thickness overlying sand. It was shown that the most important source of salts causing deterioration was that present as a zone of accumulation in the soil crust. A further conclusion reached was that prior to the introduction of irrigation the soil profile represents complete salinisation of the soil with reference to the local meteorological conditions. Under such conditions the salts are static but as is indicated in the report of the Chemical Section, there is a seasonal upward and downward movement of these salts within the soil crust. Over a complete seasonal period, however, the total amount of salt present in the soil crust does not vary. With the introduction of irrigation salts appear to be removed from the surface layer of soil and form a zone of accumulation some distance below the surface. During the year 1938-39 investigations have been carried out to study the influence of the depth of the water-table from the natural surface and its salt content on the rise of salts to the surface. The effects of other factors such as type of irrigation and the system of agriculture have also been examined.

During Rabi 1938-39 a special girdawri of villages lying on two lines (Fig. 72) between Pindi Bhatian and Qila Dharani Singh and between Chiniot and Sayedwala was undertaken since on these lines the water-table was known to vary considerably in depth. The results of this girdawri are given in Table 30. A soil survey of the areas has shown that the thickness of the soil crust does not exceed ten feet. From Table 30 it will be seen that land is going out of cultivation due to the appearance of thur at all depths of the water-table between 9 and 40 feet. As the water-table can have no connection through the sand layer with the soil at depths such as 40 feet, the conclusion must be drawn that the water-table is not an essential factor influencing the formation of thur. The investigation was extended to examine the soil profiles in those areas which are still regarded as good and those in which thur has already appeared. The results of three such profiles for the same area are given in Fig. 73. From a study of the curves presented in Fig. 73 the following conclusions have been drawn:—

(a) In the field (Pit No. 1) which was formerly under cultivation but which has become thur, the salt content is high throughout the depth of the soil crust, i.e., a depth of 10 feet from the natural surface. The main zone of accumulation, however, is 0' to 5'.

that the characteristics were fully developed and a visual examination became possible. Within a period of three weeks signs of salt efflorescence were visible at some distance below the natural surface. From an examination of the coloured illustration it is clear that the soil from the natural surface to a depth of about three feet is free from salts. From the third to the fifth feet the efflorescence is of moderate intensity. The column, sixth to the tenth feet, has a high salt content and has developed hexagonal shaped cracks. Salt is present between the tenth and the eleventh feet. Below this depth sand occurs which is free from salt. The layer between the sixth and the tenth foot when tested was found to be alkaline. This field may be classed as capable of giving good yields at present but is in danger of early deterioration due to thur.

In an adjoining field where cotton was in an excellent condition and which in the opinion of the zemindars was likely to develop thur, another profile was exposed. After a period of one month the profile was examined, and the upper limit of the salt layer was noticed to be at a depth of about one foot from the natural surface. Observations were continued on this pit and, during the period January to the end of March, the salt travelled up to the surface thus causing the land surrounding the pit to become 'Thur'. The zemindars have now left this field out of cultivation.

An examination of the profile illustrated in Fig. 76 shows that the general characteristics of salt appearance in the soil crust are the same as in the case of the profile represented by Fig. 75. The soil crust is 12 to 13 feet thick but the upper edge of the zone of accumulation of salts has taken more or less a parabolic form. The cause of this peculiar shape of the movement of salts has been investigated. Samples were taken from near the edge of the salt layer on both sides and also from the rest of the profile. These samples were examined for total salt content, pH value and total clay content. The results are represented in Fig. 77. From an examination of Fig. 77, the following conclusions can be drawn :—

(i) The peculiar shape of the zone of accumulation of salts is due to differences in the clay content of the soil. Where the clay content is high the salt has travelled upwards much faster than where the clay content is relatively low. This confirms the conclusion given in the report for the year 1938 wherein it was stated that the alternate fields of thur and normal soils were due to the differences in the mechanical composition of the fields. This also explains why, in an aerial photograph, where salt is present in the soil crust, thur fields exist side by side with fields which are under cultivation.

(ii) In the zone where the accumulation of salt has been intense the salts have re-acted with the clay portion of the soil and have converted that layer of the profile into sodium soil. The pH values in this zone have risen as high as 9·98. Even though the salt content of the soil above this zone is high the salts have not yet had time to re-act with the clay complex and the pH values are, therefore, low. If steps are not taken to check the rise of the salts to the surface or to reclaim the soil now or immediately after the first signs of thur are visible and to remove the whole of the salt from the soil crust to the water-table the reaction between the sodium salts and the clay will continue and result in the formation of an alkaline soil. The land will pass from the normal to the thur stage and ultimately to the rakkar stage when reclamation will be uneconomic.

During inspections it has become evident that a visual examination of the zone of accumulation of salts in the soil profile appeals more to the l [illegible] alyses. It is proposed to continue [illegible] ld weather. A large number of s [illegible] fferent degrees of deterioration [illegible] and position of the zone of accumulation which can produce an efflorescence at the surface will be determined.

Discussions with zemindars have shown that the development of thur is not a gradual process. In fact, just before a field is likely to become thur it gives an excellent crop. This means the transition from non-thur to thur land is sudden. These observations are important as they lend support to the view that the salt in the water-table has little to do with the formation of thur in areas where the soil crust is 10 feet or more in thickness. If salt in the water-table were responsible for the accumulation of salts at the surface then the deterioration due to salts should be gradual and not sudden since the zone of accumulation could only occur at the surface under these conditions. It has been mentioned already that with a zone of accumulation of salts some distance below the surface, yields of cotton have been above normal. It is important, therefore, to realize, that the presence of good crops does not mean the absence of danger. The true conditions of any one area can only be determined by a soil survey and the examination of the soil profiles.

Having shown that the formation of thur is due to the upward movement of the zone of accumulation of salts in the soil crust, experiments were started to study the distribution of salts in the soil profile under different crop rotations. These investigations are being

carried out at the Jaranwala Farm, a brief account of which was given in the Annual Report for the year 1938. In that report the effects of irrigation for cotton and rice on the distribution of salts in the soil profile were compared and it was stated that, whereas the irrigation of cotton led to an accumulation of salts at some distance below the surface, the irrigation of rice removed the excess of salts into the underlying sand layer.

Observations during 1938-39 have shown that in some of the plots which carried crops such as cotton or wheat, thur has appeared at the surface in patches. No signs of thur are, however, visible in fields in which rice was sown. A detailed study of the soil profiles under different crop rotations is being carried out. The results obtained so far are shown in Fig. 78.

In the case of the rotation fallow-wheat, the salts are forming a zone of accumulation between the 4th and the 12th feet. With the rotation cotton-fallow the zone of accumulation of salts lies between the 2nd and the 9th feet. The rotation rice fallow has washed most of the salt from the soil crust into the sand layer. There is some accumulation at the 12th foot. As this is in the sand layer it will in all probability be incapable of returning to the surface. This view is confirmed by an examination of the fourth curve which represents the results of the rotation rice-berseem. In this case there is no zone of accumulation of salts in the profile. The salts have all been removed into the sand and the heavy irrigation given to berseem has dispersed them. Here it may be mentioned that during reclamation the sowing of a berseem crop after a successful rice crop is always insisted upon. It will be seen, therefore, that with the adoption of the methods for reclamation of land developed at the Irrigation Research Institute, permanency of land reclamation seems to be assured.

A subject now receiving considerable attention is the water requirements of crops. This can be considered from two points of view. The object of the Irrigation Branch, being a Revenue Department, is to secure the maximum outturn of crop per cusec day of water. The experiments carried out by the Agricultural Department have been made with the object of securing the maximum outturn of crop per acre sown. In neither of these views has any consideration been given to the relation between the irrigation load and the deterioration of soil due to the movements of salt to the surface. From the discussion in the previous paragraphs it is clear that the greater the area upon which a given amount of water is spread, in order to mature crops such as cotton and wheat, the less will be the downward movement of salts. It is suggested, therefore, that in all future work on the water requirements of crops, while the maximum outturn of crops per acre and the maximum outturn per cusec of water should continue to be considered, a further point for examination should be the possibility of the deterioration of land due to salt accumulation on account

of light irrigation. The problem is not so simple as it looks. On account of the increase in the rural population and the fragmentation of holdings the only way to support the family is to cultivate a much larger area than formerly. As the water-supply cannot increase to correspond with the increase in population, deterioration of land under the present system of agriculture must, therefore, be inevitable.

The experiments on reclamation which have been carried out have shown that salt can be removed from the soil crust by the growth of rice and berseem and that the reclaimed land can produce excellent crops of cotton, wheat, sugarcane, etc., for a period of 8 years without showing signs of deterioration. It is suggested, therefore, that the agricultural system of deteriorated and danger areas should be altered so that rice can be included in the rotation. The evidence at present available shows that the introduction of rice should not be necessary more than once in 9 years and possibly for a much longer period. The introduction of rice into areas now under perennial irrigation presents some difficulties. But if either new Kharif channels can be specially constructed or the present ones enlarged to carry increased summer supplies then a remedy for deterioration becomes available.

2.—Reclamation of Thur Land.

(i) *Renala Estate.*—In the reports for the Chemical Section for the years 1937 and 1938 it was mentioned that in the Punjab alluvium the water-table is always in the sand layer and that when it touches the soil crust it is unable to rise any further if the soil crust is from 6 to 10 feet in thickness. Numerous soil profiles examined during 1938-39 confirm this view. Advantage was taken of this observation in formulating a policy for the reclamation of thur land. In all previous experiments reclamation was undertaken with a system of field and subsidiary drains. This procedure makes land reclamation expensive. The cost of land occupied by the drains and the cost of the maintenance of the drains are debited to the cost of reclamation. As the water-table is unable to rise through the soil crust if it is more than six feet in thickness, the construction of a drainage system under these conditions becomes unnecessary.

In the discussion of the movement of salts in the soil profile it has been shown that the salts, if they are removed from the soil crust to the water-table, are unable to rise again to the surface. From these considerations it was decided to undertake reclamation of thur land in the Renala Estate without a system of field drains. A plan of the areas where reclamation was undertaken is shown in Fig. 79. Reclamation was started in two separate blocks: Block A which is situated in the depression below the dhaya and in which the water-table is at a depth of 7·0 feet below the natural surface and Block B which lies on the dhaya and has a deep soil profile. The water-table in this block is at a depth of 17 feet from the natural surface.

At the beginning of the experiment fears were expressed that in the depression the water-table under rice irrigation would rise to the surface and would make the land waterlogged. It was also considered that the sub-soil drainage water from the dhaya, which was salt, would travel towards the depression and would spoil the area again. In order to obtain data on these two important questions observation pipes were installed both on the dhaya and in the area in the depression. A third pipe was installed at the deepest point in the trough. The results obtained showed that both in the dhaya area and in the area under reclamation in the depression a local rise in the sub-soil water-level took place under rice irrigation. When irrigation was stopped and the rice harvested the water-level fell to its original level. The results for the area in the depression are plotted in the form of a curve in Fig. 80. Observations of the third pipe installed at the lowest part of the trough showed that the water-level in the pipe was not affected by the leaching of the neighbouring thur land or the land on the dhaya. When, however, irrigation was applied to the field in which the pipe was situated the water in the pipe rose.

These observations are important as they indicate that the leaching of thur land is not likely to cause any damage to other lands in the vicinity. It seems the salts when they are added to the water-table move along with it and join the main sub-soil water stream.

Samples of sub-soil water were taken during the course of the experiment and were examined for salt content. The results are shown in Fig. 81. It will be seen that in Block A, where flow takes place in a fully saturated profile, the whole of the salt in the soil profile has been removed to the water-table. The salt content of the sub-soil water is lower after than before reclamation. In Block B., i.e., on the dhaya the salt from the soil profile was added to the water-table and raised its salt content from about 300 parts per 100,000 to about 1,460 parts per 100,000. With the movement of the sub-soil stream and further additions of water at the surface of the land, the salt content of the water has a tendency to fall. It is proposed to continue these observations.

The results of the analyses of soil profiles from the depression in Block A and of the dhaya, Block B, before reclamation are given in Table 31. It will be seen from the results in Table 31 that the Ren soils represent typical thur land. The salt content of the surface in the depression is high and the pH value is low. On the dha[illegible] however, the land is salt to a depth of approximately 13 feet.

As orders for reclamation were received late leaching [illegible] not started till after the 25th of June, 1938. Observations show that both in blocks A and B leaching was very rapid. Whereas [illegible] Block A the growth of grass during leaching was good, in the up[illegible] parts of the dhaya, due to the high salt content in the sub-soil laye[illegible]

grass did not become established before the transplanting of rice. Both in Block A and the lower parts of Block B the growth of rice was very satisfactory. After the harvesting of rice, berseem was grown in all the fields from which rice was removed early and senji in those where rice was harvested late. Berseem and senji made good growth in most of the fields. An examination of the fields under berseem and senji was carried out. The results are given in Table 32. It will be seen from these results that in good berseem fields the salt content as well as the pH value of the soil profile is low which indicates that a cotton crop can be sown in these fields and that the yields of cotton will be good. The results at Renala confirm the previous practice of judging the rotation from the condition of the berseem following rice.

Two important conclusions can be drawn from the one year's reclamation in the Renala Estate :—

(1) If reclamation of 'Thur' land is undertaken at an early stage after the appearance of the salt efflorescence, reclamation can be completed with one rice crop.

(2) If the sub-soil water as measured by a fresh boring, is more than 5 feet below the surface the construction of the field and subsidiary drains is not necessary. This, in turn, reduces the costs of reclamation.

(ii) *Sher Mohammadwala.—Lower Jhelum Canal.*—A block of 50 acres of old kallar land was taken up for reclamation during 1936. As the salt content of the soil was high and the degree of alkalization was low leaching was rapid under rice. Whereas quick leaching of the soil reduced the yield of rice it enabled the land to be reclaimed much more quickly. The Kharif closures in the Lower Jhelum Canal are also partly responsible for the low yield of rice.

From an examination of fields under rice during 1937 it was known that almost the whole of the salt had been removed from the soil crust into the water-table which indicated that other crops could be introduced into the rotation. During Kharif 1938, 15 acres of reclaimed land were put under cotton which gave an average yield of 9·5 maunds of cotton per acre.

The reclamation at Sher Mohammadwala has been done entirely by the landlord's tenants, the only direct labour employed, during the course of reclamation, being the labourers required for the irrigation of fields during leaching and the growth of rice. Accounts have been maintained which show that the total expenditure of the landlord on reclamation, till the end of Kharif 1938, has been Rs. 492. The total income from the landlord's share of the produce amounts to Rs. 1,278. If the share of the pay of the muqaddam in charge of reclamation is also included in the expenditure the total expenses would be Rs. 852. Thus on an area of 50 acres there is a profit of Rs. 426

to the landlord during the course of five harvests. The experiment is still in progress. The landlord, however, is convinced of the method of reclamation. He has now purchased an additional supply of 1·5 cusecs of water from the Irrigation Branch which he is utilizing for the reclamation of other thur land.

(*iii*) 97/9-L.—*Lower Bari Doab Colony*.—97/9-L is another example of old kallar land. During the course of the survey it was found that all types from the ordinary kallar to the mild rakkar and the heavy rakkar types, locally known as 'bara' existed in the same locality. On orders from the Chief Engineer, the kallar area in squares 48 and 49 of the village was selected for experiment. Leaching was started in April 1938. The Jhona variety of rice was transplanted in an area of 11 acres, which gave an average yield of 13 maunds of rice per acre. An examination of the fields under rice was made. The results of analyses are given in Table 33. These results show that with one rice crop the depth to which the salts have been removed varies with different fields. Whereas in field 17/A of square 48 not more than two feet of soil has been freed of salt, in other cases salts have been washed from about five feet of the soil. In one case, field 19/B, of square 48, the salts have gone down to a depth of 11 feet. As the salt content is generally high within 10 feet of the soil surface it is proposed to sow rice till the whole of this column of soil is free from salt.

In the discussion on the subject of the movement of salts and the formation of thur, it was stated that thur was on the increase even in areas where the water-table is deep. It was also shown that due to the action of the sodium salts on the clay content of the soil the lower layers of the profile had become alkaline. With the object of studying the progress of reclamation on such areas and the effect of leaching and the growth of rice on the salt content and the degree of alkalization of the lower layers of soil, two new experiments have been started in the Lower Bari Doab Colony.

In Chak 97/9 L a field has been selected where the depth to water-table is 45 feet. It has a soil crust of 28 feet, a high salt content and a high pH value throughout the profile. The results of analyses are given in Table 34. It is proposed to put this field under leaching during Kharif 1939 and to make an examination of the whole of the profile after every rice crop.

In Chak 11/4 L in the same Colony the water-table is 30 feet deep. Although the salt content is high throughout the depth of the soil crust of 21 feet, the pH values are not as high as in the case of 97/9 L. The results of analyses are given in Table 35. After every rice crop the profile will be examined.

(*iv*) *Introduction of Hill Rice in the Reclamation of Thur land*.—It has been stated that in certain soils whose salt content is high and the degree of alkalization low leaching is very rapid. Water,

therefore, cannot stand in rice fields and in consequence the yields of rice are low. Although, as has already been shown, the reclamation of land is more readily effected under these conditions, the low yield of rice reduces the profit on reclamation. Further the amount of water used under these conditions is probably considerably in excess of that required for reclamation and is, therefore, wasted from the reclamation point of view. In order to obtain normal yields of rice under these conditions and to limit the amount of water used to that required for the actual removal of salts it is proposed to introduce the barani hill varieties of rice. These barani varieties of hill rice are grown in the Kulu Valley where, naturally, they receive only intermittent irrigation in the form of rain which quickly drains off. As conditions in plots under reclamation where leaching is very rapid, are similar to those of the barani areas of the hills it is expected that the introduction of hill varieties of rice during reclamation will be successful. An experiment in this direction was carried out at the Chakanwali Reclamation Farm where the yield of hill rice, under intermittent irrigation, was approximately 35 maunds per acre.

(c) *Chak 188-N.-B.,—Lower Jhelum Canal—And The Permanency of Reclamation.*—The conditions governing the permanency of reclamation have been fully discussed in the report for 1938. In the discussion on the movement of salts in soil profiles it has been shown that if in reclamation the salts have been completely removed from the soil crust to the sand layer, the soil should be regarded as permanently reclaimed. The yields of crops obtained from reclaimed land in 188-N. B. were discussed in the report for the year 1938, and it was stated that no decline in yields had taken place. These observations were continued during the year. During 1938 the yields of cotton from reclaimed fields were as high as 15 maunds per acre. A photograph of one of the cotton fields is shown in Fig. 82.

3.—Soil Surveys.

(i) *Survey of land lying on both sides of the Lower Raniwah Drain.*—Statements have been made that the salt water carried by drains from one part of the doab to the other would be lost by seepage through the bed of the drain and would cause deterioration of the land adjoining it. With a view to verifying these statements a study of the Lower Raniwah Drain of the Chaj Doab was carried out. A complaint had been received that one well alongside the drain had become saline and that the land on the well was deteriorating.

In the first instance careful discharge observations at various sites of the drain were made to determine the reaches where the drain was losing water through its bed. These observations showed that approximately three cusecs of water containing 600 parts per 100,000 of salt were being lost between R. D. 186,000 and R. D. 156,000 of the drain. This loss is due to the excessively sandy nature of the soil. The complaint about the deterioration of land did not relate to this area but to a place near R. D. 238,000 of the drain. Evidently the seepage from the drain between R. D. 186,000 and 156,000 cannot be the cause of the appearance of thur in land situated at R. D. 238,000. The cause of the deterioration of land at R. D. 238,000 has also been investigated and will be referred to later.

It has already been stated that the salt content of the water in the drain at R. D. 186,000 is approximately 600 parts per 100,000 of water. At its tail, where the drain joins the river creek, the salt content of the drain water is also about 600 parts per 100,000. In order to find the effect of seepage from the drain on the adjoining wells water samples from wells situated on both sides of the drain were taken and were examined in the Institute. The position of the wells and the salt content of the waters in the wells are shown in Fig. 83. With the exception of three wells situated on the left side at R. D. 105,000, right side at R. D. 185,000 and R. D. 140,000 the salt content of all the other wells is on the high side. It is well known that the sub-soil water of the Lower Jhelum Colony has a high salt content and is seldom used for drinking. The salt content of the well waters in the reach R. D. 186,000 and R. D. 156,000 where seepage is taking place is, if at all, lower than either the reach above it in which 8 cusecs of salt water are passing in the drain or in the lower reach where the quantity of water in the drain is much less. This indicates that the salt water lost through the bed of the drain does not add to the salt content of the water in the adjoining open wells. This is a further proof that water in the water-table is in motion and, that, during reclamation if salts are washed from the soil profile to the water-table, they are not likely to return again to the surface nor affect the adjoining lands.

The investigation was extended to the examination of some soil profiles and sub-soil waters on both sides of the drain. For this purpose soil profiles were dug on both sides at various distances on a line perpendicular to the drain at R. D. 230,000 and 238,000 of the drain, for it is in this reach that complaints of soil deterioration have been made. One such section is shown in Fig. 84. The salt content and the pH values of foot columns in the profiles and the salt content of the sub-soil waters are shown in the plan. From a study of the data given in Fig. 84 the following conclusions are drawn :—

(*a*) The salt water in the drain does not affect the salt content of the water obtained in the soil profiles dug alongside it. It is no doubt true that in one case on the left of the drain the salt content of the sub-soil water is as high as 407 parts per 100,000 but this seems to be due to the presence of the salt in the soil profile rather than to the salt in the drainage water, since the water obtained from the profile dug nearest to the drain on the same side shows a salt content of only 66 parts per 100,000.

There is no gradual decrease in the salt content of the sub-soil waters on either side of the drain which again indicates that the variations in the salt content of the waters are due to local causes rather than to any effect of the drain.

(*b*) Examining the salt content and the pH values of the soil profiles the conclusion drawn is the same as in the case of the sub-soil waters. The salt contents of soil profiles nearest the drain, which are liable to greater contamination than the rest, are the lowest. This is also the case with the pH values. The conclusion again is that the variations in the salt content and the pH values are due to local variations in the soil rather than to any effect of the salt in the drainage water. It is true that kallar soils exist alongside the drain in its tail reach. Enquiries made show that the land lying between the fork of the two rivers, Jhelum and Chenab, has always been salt.

During the course of the enquiry certain facts which have a bearing on the deterioration of land in this locality came to notice. These are important as, if steps are taken to remove them, the areas still under cultivation can be saved from deterioration. During 1929 when a flood occurred in the Mona Drain, the flood water, having breached the Sulkhi Branch [illegible] ame as far as the tail reach of the Lower Raniwah Drain and [illegible] ulated there. As this passed through

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In the first instance careful discharge observations at various sites of the drain were made to determine the reaches where the drain was losing water through its bed. These observations showed that approximately three cusecs of water containing 600 parts per 100,000 of salt were being lost between R. D. 136,000 and R. D. 156,000 of the drain. This loss is due to the excessively sandy nature of the soil. The complaint about the deterioration of land did not relate to this area but to a place near R. D. 238,000 of the drain. Evidently the seepage from the drain between R. D. 136,000 and 156,000 cannot be the cause of the appearance of thur in land situated at R. D. 238,000. The cause of the deterioration of land at R. D. 238,000 has also been investigated and will be referred to later.

It has already been stated that the salt content of the water in the drain at R. D. 136,000 is approximately 600 parts per 100,000 of water. At its tail, where the drain joins the river creek, the salt content of the drain water is also about 600 parts per 100,000. In order to find the effect of seepage from the drain on the adjoining wells water samples from wells situated on both sides of the drain were taken and were examined in the Institute. The position of the wells and the salt content of the waters in the wells are shown in Fig. 83. With the exception of three wells situated on the left side at R. D. 105,000, right side at R. D. 135,000 and R. D. 140,000 the salt content of all the other wells is on the high side. It is well known that the sub-soil water of the Lower Jhelum Colony has a high salt content and is seldom used for drinking. The salt content of the well waters in the reach R. D. 136,000 and R. D. 156,000 where seepage is taking place is, if at all, lower than either the reach above it in which 8 cusecs of salt water are passing in the drain or in the lower reach where the quantity of water in the drain is much less. This indicates that the salt water lost through the bed of the drain does not add to the salt content of the water in the adjoining open wells. This is a further proof that water in the water-table is in motion and, that, during reclamation if salts are washed from the soil profile to the water-table, they are not likely to return again to the surface nor affect the adjoining lands.

The investigation was extended to the examination of some soil profiles and sub-soil waters on both sides of the drain. For this purpose soil profiles were dug on both sides at various distances on a line perpendicular to the drain at R. D. 230,000 and 238,000 of the drain, for it is in this reach that complaints of soil deterioration have been made. One such section is shown in Fig. 81. The salt content and the pH values of foot columns in the profiles and the salt content of the sub-soil waters are shown in the plan. From a study of the data given in Fig. 81 the following conclusions are drawn :—

(a) The salt water in the drain does not affect the salt content of the water obtained in the soil profiles dug alongside it. It is no doubt true that in one case on the left of the drain the salt content of the sub-soil water is as high as 407 parts per 100,000 but this seems to be due to the presence of the salt in the soil profile rather than to the salt in the drainage water, since the water obtained from the profile dug nearest to the drain on the same side shows a salt content of only 66 parts per 100,000.

There is no gradual decrease in the salt content of the sub-soil waters on either side of the drain which again indicates that the variations in the salt content of the waters are due to local causes rather than to any effect of the drain.

(b) Examining the salt content and the pH values of the soil profiles the conclusion drawn is the same as in the case of the sub-soil waters. The salt contents of soil profiles nearest the drain, which are liable to greater contamination than the rest, are the lowest. This is also the case with the pH values. The conclusion again is that the variations in the salt content and the pH values are due to local variations in the soil rather than to any effect of the salt in the drainage water. It is true that kallar soils exist alongside the drain in its tail reach. Enquiries made show that the land lying between the fork of the two rivers, Jhelum and Chenab, has always been salt.

During the course of the enquiry certain facts which have a bearing on the deterioration of land in this locality came to notice. These are important as, if steps are taken to remove them, the areas still under cultivation can be saved from deterioration. During 1929 when a flood occurred in the Mona Drain, the flood water, having breached the Sulkhi Branch, came as far as the tail reach of the Lower Raniwah Drain and accumulated there. As this passed through

a salt area it carried with it a large quantity of dissolved salts. Measures should be taken to prevent a recurrence of this nature.

The Lower Raniwah Drain has no left bank from R. D. 42,000 to R. D. 237,000. There are several reaches where during the monsoon months even a moderate flood in the drain spills over and spreads on to the adjoining land. It is known that sometimes a depth of water varying from ·5 to 1·5 feet stands on the land for a period varying from three days to three weeks. It has been mentioned already that the drainage water is salt and the spilling of such drainage water is likely to add considerable amount of salt to the land. The spilling of the drainage water on the adjoining land should be prevented.

(ii) *Abandoned Chakanwali Reclamation Farm.*—For the study of waterlogged, Thur and Rakkar lands and for determining the methods of reclamation of these types, Chakanwali Reclamation Farm was opened in the year 1926. A brief account of the farm and the work carried out during the period 1932 to 1936 is given in the Annual Reports for the years 1935 and 1936.

In the year 1936 Government issued orders to close down the farm and hand over the reclaimed areas to a lessee. This was done by the Civil Department. As the terms of the lease were very mild, the lessee neglected the drainage system and also the cultivation of some of the reclaimed land.

Under instructions from the Chief Engineer a soil survey of the abandoned farm was carried out during the cold weather 1938-39 to investigate if any soil deterioration had taken place during the period the land has been on lease. The results of the soil survey are given in Table 37. For reference a plan of the farm is given in Fig. 85. It is proposed to deal with Table 37 in some detail. There were three main types of land taken up for reclamation at Chakanwali. They were as follows :—

(a) Waterlogged land adjacent to the canal and represented by plots S, U, W, Y, C, B, and E.

(b) Thur land represented by Q, A/1, G/1, and F/1.

(c) Rakkar soils represented by H/1 and C/1.

(a) *Waterlogged area.*—At the time of handing over, the drains in this area were maintained and as a result, even when the canal was running full supply, the water-table was situated at a depth of 1½ to 2 feet below the soil surface. In some portions of these plots now even when the canal is not running full supply, water is standing on the fields and in no case does it appear to be deeper than 6" below the soil surface. The soil in these plots is very light and there is practically no soil crust.

When the waterlogged area was handed over it was carrying a good crop of sugarcane which had been sold in the previous years

for Rs. 4,800 (plots C, F and S only). Since handing over owing to the lack of inter-cultivation sarkanda has invaded the area and has crowded out the sugarcane to such an extent that none now exists. Instead the land is used as a pasture and in certain parts the grass is good.

(b) *Thur Soils.—Plot A/1.*—This plot was a typical salt area before reclamation. It was first taken up for reclamation in 1931. It was reclaimed during this year and had carried crops between 1932 and 1935 of sugarcane, cotton, wheat, senji, berseem and chillies. The yields of these crops during this period indicated that the reclaimed land might be considered first class. The analyses given in the table for this plot show that it is still in a condition to produce excellent crops. Wheat had been sown and the crop appeared to be fairly good and even. The preparation of the seed bed had been a very superficial matter as it was noticed that large clods of earth existed. Both from the state of the crop and the figures for the analyses it can be stated that deterioration has not again set in although the soil crust is not more than 3 feet thick and the water-table in the underlying sand is touching the soil crust. The water-table has a conductivity of 1,250, which means that it is saline. In this plot the field and the subsidiary drains had ceased to function so that the water-table as indicated by the water standing in the drains was within 3 feet of the surface. The area had formerly been irrigated but on handing over to the lessee the water-supply at the outlet serving this area had been reduced. No irrigation had been given to this area since handing over. As no irrigation had been given there would be little tendency for salt movement downwards. The conditions were more suitable for salt movement upwards. Since the analyses do not show this upward movement by the accumulation of salt in the surface layer it indicates that the reclamation, once the salts have been removed from the soil crust, is likely to be permanent even under the worst agricultural and sub-soil water conditions.

Plots G/1 and Q have also been sampled and both from the analyses and the inspection of the crops it can be stated that the remarks made as regards A/1 apply to these areas as well. Plot F/1 was not sampled as it was adjoining A/1 and G/1 and appeared to be similar in condition to these plots.

(c) *Rakkar Soils.—Plot H/1.*—This plot was taken up for reclamation in 1931 as an experimental measure to determine the difficulties that would be met with in reclamation of soils of this type. The initial pH value of the soil in this plot was over 10·0 and it represented some of the worst land to be found in the Punjab. The bad condition of the land was entirely due to its high alkalinity. Some idea of the poor state of the land is given by the fact that the maximum yield of rice obtained from any field in this plot was not more than

4 maunds per acre during the first year of reclamation. From the analyses given in the table it will be seen that at the present time the pH value of the soil and the total soluble matter present are such as are found in fairly good land. At the end of 1935 four crops of rice had been grown and it was considered that the majority of the land had been reclaimed. In some portions of the plot berseem and sugarcane had been introduced after three rice crops and had made good growth. This area is still under cultivation, the rice stubble indicated fairly good yields and the crop of wheat on some of the fields was making good growth.

As the area is still under crop and as the soil analyses indicate that no deterioration has taken place, it appears that the reclamation of the Rakkar type when complete is permanent. It is not, however, recommended that this type of land should be taken up for reclamation. The study of this type of land has been and is still valuable for the understanding of the processes of soil deterioration and reclamation.

(iii) *Aerial Surveys.*—In the Annual Report for 1937 the method of soil surveys by means of ærial photographs was described and it was indicated t[illegible] are more reliable than the [illegible] Revenue Patwaris. It [illegible] the interpretation of ær[illegible] with the survey carried out by the Patwari showed large discrepancies which were ultimately traced to the inaccurate records maintained by the Patwari. The matter was discussed in the Waterlogging Conference for the year 1937 and it was decided that instead of basing decisions on the comparison of only one village a whole photograph of a strip of about 14 square miles in the Sheikhupura district be interpreted and compared with the ground survey made by the Patwaris. The results of the interpretation of the ærial photograph for this strip of 14 square miles are given in Table 38. This shows that out of a total cultivable area of 8,535 acres, 3,529 acres are thur (salt) and the rest more or less under cultivation.

On account of other important work in connection with soil surveys it was not possible to make a ground survey field by field, of all the 8,535 acres but a check was made in the field in company with the Patwari responsible for the girdawri and the Qanungo of the area for the following six villages :—

(1) Bahrianwala.
(2) Jaita.
(3) Qilla Sahib Singh.
(4) Bado Murado.
(5) Qanuago.
(6) [illegible]

For the purpose of this check a statement was prepared for each village of the differences between the interpretation of the ærial photographs and the Patwari's girdawri. The check on the ground was carried out in 1939 for these fields and the results are reported in Table 39. From Table 39 it is clear that the Patwari's survey carried out in winter 1936-37, reported far less thur than is indicated actually in the field. For a total thur area of 256·5 acres that existed in Rabi 1939, 271·5 acres were reported from the interpretation of the ærial photographs whereas the Patwari's survey showed that only 83·12 acres of thur existed. Since 1937 there may have been some increase in the area under thur. But it is inconceivable that the increase, during the period of two years, would be of the order of 300 per cent. That the check on the Patwari's survey by means of the interpretation of ærial photographs has had a profound influence on his work is indicated by the figures for thur reported by the Patwari during the next harvest, i.e., Kharif 1938. Comparing the Patwari's figures for Rabi 1937 and Kharif 1938 the thur area suddenly jumped from 83·12 acres to 205·8 acres.

Judging from these figures it can safely be assumed that the annual deterioration of 50,000 acres of land due to thur reported by the Patwaris is a very conservative estimate. The damage is much more than this. As has already been mentioned, special surveys show that land is going out of cultivation at a rapid rate even in areas with a deep water-table. It seems important therefore that the extent of damage due to thur should be investigated as early as possible and, as the progressive deterioration is great, this information should be obtained in the least possible time The quickest and the cheapest method of obtaining the information is the taking of ærial photographs of the doabs in which land deterioration is taking place and their interpretation in the Institute.

4.—Miscellaneous.

(i) *The Examination of Drainage waters of the Chaj and the Rechna Doabs.*—With the development of canal irrigation and the consequent rise of water-table in the Punjab has arisen the question of drainage. The problem of the rise in water-table and the extent to which drainage is essential for the Upper Chenab Canal area has been dealt with in a previous publication of the Institute. In the vicinity of some of the main canals and branches the water-table had risen to the ground surface. Since the year 1908, which was a record year for rainfall and which was the main cause of a permanent rise of a high order in the water-table of most of the canal irrigated tracts, the Irrigation Branch has studied the question of land drainage much more closely.

In the first place the construction of the main drains for areas where waterlogging had actually occurred was started. Later, a five year programme of drainage for removing rain water quickly

from the Chaj and the Rechna Doabs was taken up. Most of the main drains have been constructed. A programme for the construction of the branch drains is now in hand.

With the development of drainage has arisen the question of the disposal of drainage waters. With this end in view a regular examination has been made of waters from the major drainage systems of the Chaj and the Rechna Doabs the results of which are discussed below.

The Chaj Doab.—In the Chaj Doab which lies between the rivers Jhelum and Chenab are situated two main drainage lines. Towards the Chenab side is the Budhi Nallah which starts near Gujrat travelling south-west as far as Ahmedwala where it joins the river. It is interrupted in many places by sandy channels, small and large, which have evidently been occupied by the river at various periods and which are at places about 10 feet below the level of the adjoining country and 100 yards across. The whole of the Budhi Nallah drainage system has not yet been developed. The first link to be constructed was the Wan Drain which has been described in detail.

Towards the Jhelum side, the main natural drainage starts north-east of the town of Miani and travelling parallel to the river discharges into it near village Kabra in Jhang district. This drainage is known as the Raniwah Drainage.

In Fig. 86 are shown the main, the branch and the subsidiary drains that have either been constructed or are proposed to be constructed.

The Wan Drainage System.—This is a net work of several small drains forming more or less a complete circle which drains the area between the Chenab Escape on the north-east side and the Southern Branch Lower Jhelum Canal on the north-western portion. Bhabra Drain is also a link of the Wan Drainage system. The total catchment area of the Wan system of drains is of the order of 28 square miles. It is a system of seepage drains carrying the waters of the waterlogged area of the depression between the Southern Branch and the Chenab Escape Channel.

Samples of water have been taken every month from 1935 to date from the point where the Main Wan Drain starts and also at its tail, i.e., R. D. 37,500. At this place the waters from the drain are pumped into the Khadir Branch the pumps being worked by means of a water turbine when the canal is in flow and by means of Rustan Engines when it is closed. Samples have also been taken of the mixed canal and drain waters at a distance of 1,000 feet downstream of the point at which drain water is pumped into the feeder. Table 40 gives the discharge of the drain at its tail and also the results of the analyses of waters for the whole of the period for which the waters have been examined. From the results presented in this table it will be seen

that the salt content of the waters in the drain and of the mixed waters in the Khadir Branch have never exceeded 60 parts per 100,000. It has already been shown that waters having a salt content of less than 60 parts per 100,000 of water are suitable for irrigation, i.e., they do not cause any deterioration of land. The waters from the Wan Drainage system have, therefore, been recommended for irrigation either direct or after having been mixed with canal water. The pH values indicate that the waters are not very alkaline.

The Raniwah Drainage System.—As has been mentioned above, this drainage starts north-east of the town of Miani and discharges into the river Jhelum near village Kabra in the Jhang district. It is crossed by the Sulki Branch Lower Jhelum Canal and a cut has been excavated along this branch to lead the discharge of the portion of the drainage upstream of this crossing to the Sulki Escape and on to the river. The portion of the drainage above the Sulki Branch Crossing is known as the 'Mona Drain'. The portion lying below the Sulki Branch crossing is known as the Lower Raniwah Drain.

The Mona Drain.—Mona Drain starts from the right side of the Main Line, Lower Jhelum Canal, near R. D. 166,000 and, taking the waters of the depression in villages Pakhowal, Mona and Pind Makoh, travels more or less parallel to the river Jhelum when it is joined by the cut made to de-water the Nabi Shah Jheel area. It pours its waters into the Sulki Creek which in turn joins the river Jhelum.

During its passage Mona Drain is crossed by a number of private inundation canals and, on occasion, acts as an escape channel for some of these channels. In times of abnormal discharge in the Mona Drain water is escaped into the Bhek Drain through the Syphon at R. D. 65,000 Sulki Branch which in turn goes into the Lower Raniwah Drain. The total catchment area of the Mona Drainage system is approximately 476 square miles.

Samples of waters from this drain have been collected from R.Ds. 13,200, 135,000, 327,500 and also from the Sulki Creek. The results of analysis for samples taken at R. D. 327,500 for the period 1932 to 1938 are given in Table 41. It will be seen from this table that, except on very rare occasions, the salt content of the water in this drain is never less than 60 parts per 100,000. On the basis of excessive salt content these waters have been declared unsuitable for irrigation. The pH values, however, indicate that their alkalinity is low. The results, over a period of four years, indicate that there is no tendency for the salt content of waters in this drain to decrease. It is proposed to continue these observations with a view to investigate the possible effect of the continued irrigation of the catchment area of this drain and the consequent leaching that takes place on the salt content of the drainage waters.

The Lower Raniwah Drain.—The Lower Raniwah Drain has its beginning in the Bhek Main Drain which starts near R. D. 65,000 of the Sulki Branch, opposite the point where the Mona Drain enters the Sulki Creek. Lower down the Bhek Main Drain is joined by the Bhek Branch Drains and also the drains emptying the depression in the Sargodha Remount Depôt.

Before the construction of the full Lower Raniwah Drain the Bhek Drain used to end near R. D. 40,000 of the Faruka Distributary at which place the waters from the Bhek Drain were pumped into the distributary. Careful records of the examination of drainage waters, since the construction of the Bhek Drain and the installation of the pumping plant at the Bhek Pumping Station, are available. The results of these analyses are presented in Table 42 and the salt content alone of the water from the Bhek Drain is shown in the form of a curve in Fig. 87. From the results presented in Table 42 and Fig. 87 it can be concluded that the salt content of the Bhek Main Drain rose consistently from 240 parts per 100,000 in 1931 to about 376 parts in 1933. It fell to about 350 parts in 1935-36. To start with the pumping from the drain was not very large but when it increased to 16 cusecs and later to 18 cusecs the salt content of the mixed waters in the Faruka Distributary increased beyond the limit at which water is considered safe for irrigation. Under the advice of the Institute pumping was, therefore, reduced to only 8 cusecs. The Bhek Pumping Station was stopped on 21st June, 1936, when the Lower Raniwah Drain was opened.

With the construction of the Sargodha Remount Depôt Drains and the consequent opening of the Lower Raniwah Drain the salt content of the drainage has considerably increased. The results of the analyses of waters from the tail reach of the Lower Raniwah Drain are given in Table 43. These results show that the salt content of the waters in the Lower Raniwah Drain are very high. These waters should not be used for irrigation.

The water-table in the head reach of the Lower Raniwah Drain is high. In the tail reach also it is again high. It is concluded, therefore, that the salt from the catchment area of the drain is being removed into the drain. Further analyses will show the improvement that takes place in the quality of the drainage waters and its effect on the condition of the adjoining land.

The total catchment area of the Lower Raniwah Drain is approximately 301 square miles.

The Rechna Doab.—Prior to the institution of the five years' drainage programme the system of drainage that had developed to any large extent in this Doab was the Vagh Nallah. In other cases where waterlogging existed drainage was provided by pumping th

The Vagh Nallah.—The Vagh Nallah is a surface drain in a low-lying tract some six miles to the South of Ramnagar. Passing through villages Ramki, Marh, Bashi, Sawanpura, Jhumb, Sire and Mehdiabad, it joins the river Chenab near Chak Bhatti. It has since been regraded so as to take the waters of the Kalerwala, the Jhattanwali and the Ahmedpur drains. These drains pass through very badly waterlogged areas on both sides of the Lower Chenab Canal, Main Line. The average discharge of the Vagh Nallah is approximately 40 cusecs during the winter months. The maximum discharge recorded during the monsoon has been 800 cusecs.

Samples of waters were taken at R. D. 22,000 of the Vagh Nallah. The results of analyses are given in Table 44. These results indicate that the waters in the Vagh Nallah are suitable for irrigation. The total catchment area of the Vagh Nallah Drainage System is approximately 450 square miles. This includes also the area on the Upper Chenab Canal lying on the left side of the Lower Chenab Canal, the storm water of which is taken up by this drainage system.

Pumping Stations.—The pumping stations shown on the map of the Rechna Doab were mainly installed to pump water from local depressions or water received as drainage from higher areas.

A statement showing the discharges pumped and the results of analyses is given in Table 45. From the results in Table 45 it will be seen that the waters pumped at the Sadkana Pumping Station have always had a high salt content and have, therefore, been unfit for irrigation. The Marh Pumping Station has been pumping water of almost the same salt content as the Sadkana Pumping Station. This is also unfit for irrigation. The waters at the Salar and the Bandche Pumping Stations and also the Pumping Stations at R. D. 80,252, Jhang Branch have, however, a relatively lower salt content than those at Marh and Sadkana.

(*ii*) *A survey of the Open Wells of the Punjab with reference to the possibility of Tube-well Irrigation.*—As regards irrigation, the Punjab plain can be considered under three types :—

(1) Tracts provided with flow irrigation—perennial or non-perennial.

(2) Tracts in which Chahi irrigation is prevalent.

(3) Tracts which are devoid of any irrigation facilities and depend upon rain for agriculture.

It is well-known that lift irrigation is more expensive than canal irrigation. For canal irrigated tracts therefore the introduction of tube-wells is out of question. Two other tracts, i.e., one that is alreay irrigated by open wells and that which is not yet provided with any irrigation are, therefore, to be considered. For both these tracts it is impossible to come to a decision unless the cost of irrigation by open wells sunk by zemindars themselves is known. That this enquiry is important can be judged from the fact that out of a total of 15 million acres 4·3 million acres are irrigated by wells. A certain amount of information on the subject is available in publications 21, 35 and 46 of the Board of Economic Enquiry but certain factors, e.g., discharge from the well and the delta used, which have a bearing on the subject, have not been taken into consideration. Moreover some tracts where well irrigation has assumed importance have not been dealt with. In order to obtain full data on the economics of open well irrigation, a detailed enquiry was set on foot and a special senior zilladar was appointed to go over the well-irrigated areas and examine selected estates. The services of the local patwari were placed at his disposal by the Deputy Commisioners of the districts. For the sake of uniformity a questionnaire was drawn up and the zilladar was asked to write the answers to these questions during the course of this enquiry. The results obtained have been summarised in Tables 46 and 47. Before discussing the results it seems advisable to give brief notes on the methods of measurements.

1. *Depth to watertable.*—Depth to well water was measured by means of a bell sounder before the well had started working. From the total depth from the topmost part of the masonry to the water surface in the well was deducted the difference between the natural surface and the top of the masonry.

2. *Measurement of discharge.*—For measuring the discharge a drum which was accurately calibrated was used. At the height

The driver on the wheel was given instructions to work the bullocks at the normal speed. About 20 such readings for filling four gallons were taken for one well and from the average of these 20 readings the discharge was worked out.

3. *Time taken to irrigate one acre.*—All possible efforts were made to obtain actual readings on the spot. For this purpose the field to which the zemindar wanted to apply water was measured. The time when the water was let in the field and the time when the field was full were noted. From the time taken and the area irrigated the total time required for irrigating one acre field was calculated. In addition enquiries were made from the zemindars themselves. It was found that in almost all cases the time taken to irrigate an acre as stated by the zemindars was nearly the same as actually observed by the zilladar.

4. *Cost of sinking a well.*—From Table 46 it will be seen that the cost of sinking a well varies very considerably. This wide variation is due to the following factors :—

(i) Depth to well water and the diameter of the well are the main factors. During this enquiry it was found that the diameter varies from 8 feet to 12 feet.

(ii) In the same locality some wells are not provided with boring pipes and strainers, others are.

(iii) Some of these wells were built during the war when labour and materials were expensive.

(iv) In certain cases the superstructure has been built in cement or cement concrete and a raised platform was constructed.

In parts of Multan district sites of old abandoned wells have been traced and the wells cleared for use.

5. *Interest and Depreciation.*—These have been worked out on the basis of rates locally prevalent.

6. *Basis of Enquiry.*—A cultivator and his family have been taken as the basis of the enquiry, i.e., the accounts are compiled for the land this farmer tills himself with his own bullocks and with the help of his own family. In certain cases this farmer does work on more than one well. It may be that he has a share on all the wells or that he may have taken land on lease on one or all the wells. An effort has been made to give his actual costs and income. In this case it is important to mention that if he is the owner of the well he has got to stand the interest and the depreciation charges on the construction of the well. But if he is a tenant or has taken land on rent the depreciation and the interest charges are included in the rent or in the terms of batai.

Discussion of Results.

Cost of acre irrigation by open wells in different parts of the Punjab.—From an examination of Table 46 it will be seen that wells with varying depths situated in various parts of the Punjab having different climates have been examined. Wells with depth varying from 4·5 feet to about 56 feet were studied. In this table three columns are the most important. They are :—

1. *Discharge from the well.*—The discharge varies from 0·06 cusec to about 0·19 cusec.

2. *Cost of one acre irrigation.*—Out of the 51 wells examined 40 are such that the cost of one acre irrigation lies between Rs. 2-8-0 and 7-8-0. There are five cases where the cost is less than Rs. 2-8-0 and about six in which it is higher than Rs. 7-8-0 per acre.

Dealing first with those wells where the cost of irrigation is very high :—

(a) *Bahaudinpur.*—This village lies in the Sirival tract of Jullundur district. Water-table in this area used to be very high in the early days. A high water-table with a high rainfall was sufficient to mature the crops. During the last 25 years the water table has fallen to a depth of 25 feet from the natural surface. The farmer whose estate has been examined was the first to instal a well which is said to have cost him approximately Rs. 1,600. Till last year he had not irrigated more than two acres in a year on this well. Interest and depreciation which amount to approximately Rs. 205 have, therefore, been debited to the total number of irrigations on these two acres. This has raised the cost. Since the installation of this well this farmer has been trying to persuade other zemindars to share his well so that he may be able to recover a part of the interest and depreciation charges from them. He is also making efforts to put more of his own area under chahi irrigation.

(b) *Dhepur.*—This village lies in the same Sirival tract and therefore the above arguments also hold good in this case.

(c) *Bassi Ghulam Hussain.*—The cultivator who is the sole proprietor of the well has put a very small area under chahi irrigation. This has, therefore, raised the costs.

(d) *Dugri.*—In this case the cost is high because the well is very rarely worked. The total irrigation during the year is not more than 6·76 acre irrigations.

From the reasons given under (a), (b), (c), (d) and (e), above it will be seen that the cost of lifting water is very high on account of abnormal circumstances. Ordinarily the cost as in the other 41 cases should lie between Rs. 2-8-0 and Rs. 7-8-0 per acre irrigation.

Dealing now with those cases where the cost of irrigation is abnormally low :—

(a) *Mukandpur.*—In this village the man whose estate is under examination has only one-third share in the well whereas due to the absence of other owners he is utilising almost half the share. He is thus able to irrigate a much larger area than he is entitled to. If depreciation and interest for half share of the well are debited to his account the cost of one acre irrigation will be approximately Rs. 3.

(b) *Chak Nizam and Taraunya in Gujranwala district.*—In the Gujranwala district some landlords have lately put in a large number of wells and have given up canal irrigation. In such cases the tenants on well irrigation have not agreed to bear any interest and depreciation charges on the well or the persian wheel.

(c) *Jarala and Dorana Langana in Multan district.*—In Multan district there are several tracts where it is very difficult to keep tenants on purely chahi irrigation. In such tracts, therefore, the landowner gets only one-third share of the produce of wheat and leaves the tenant to use all the Kharif and the other Rabi crops for himself. In such cases, as the interest and the depreciation charges on the well are not debited to the cultivator's account, the costs of irrigation have been low. There are instances where zemindars have spotted sites of old abandoned wells and have cleared them for use. In such cases the cost of construction of the well is very low and hence its depreciation and interest charges are small. As the landlords in Multan district get very little return on their chahi lands it may be concluded that they would welcome the idea of tube-well irrigation because in that case they can realize full rents.

In calculating the costs of irrigation by open wells no account has been taken of the labour required for driving the bullocks and for

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1. *Discharge from the well.*—The discharge varies from 0·06 cusec to about 0·19 cusec.

2. *Cost of one acre irrigation.*—Out of the 51 wells examined 40 are such that the cost of one acre irrigation lies between Rs. 2-8-0 and 7-8-0. There are five cases where the cost is less than Rs. 2-8-0 and about six in which it is higher than Rs. 7-8-0 per acre.

Dealing first with those wells where the cost of irrigation is very high :—

(a) *Bahaudinpur.*—This village lies in the Sirival tract of Jullundur district. Water-table in this area used to be very high in the early days. A high water-table with a high rainfall was sufficient to mature the crops. During the last 25 years the water table has fallen to a depth of 25 feet from the natural surface. The farmer whose estate has been examined was the first to instal a well which is said to have cost him approximately Rs. 1,600. Till last year he had not irrigated more than two acres in a year on this well. Interest and depreciation which amount to approximately Rs. 205 have, therefore, been debited to the total number of irrigations on these two acres. This has raised the cost. Since the installation of this well this farmer has been trying to persuade other zemindars to share his well so that he may be able to recover a part of the interest and depreciation charges from them. He is also making efforts to put more of his own area under chahi irrigation.

(b) *Dhepur.*—This village lies in the same Sirival tract and therefore the above arguments also hold good in this case.

(c) *Bassi Ghulam Hussain.*—The cultivator who is the sole proprietor of the well has put a very small area under chahi irrigation. This has, therefore, raised the costs.

(d) *Dugri.*—In this case the cost is high because the well is very rarely worked. The total irrigation during the year is not more than 6·76 acre irrigations.

(e) *Bharoke.*—The well examined had very little water in it. As constant working of the well was not possible it could not command a big area. The total irrigation is not more than 5·13 acre irrigations which is again responsible for the high costs.

From the reasons given under (a), (b), (c), (d) and (e), above it will be seen that the cost of lifting water is very high on account of abnormal circumstances. Ordinarily the cost as in the other 41 cases should lie between Rs. 2-8-0 and Rs. 7-8-0 per acre irrigation.

Dealing now with those cases where the cost of irrigation is abnormally low :—

(a) *Mukandpur.*—In this village the man whose estate is under examination has only one-third share in the well whereas due to the absence of other owners he is utilising almost half the share. He is thus able to irrigate a much larger area than he is entitled to. If depreciation and interest for half share of the well are debited to his account the cost of one acre irrigation will be approximately Rs. 3.

(b) *Chak Nizam and Taraunya in Gujranwala district.*—In the Gujranwala district some landlords have lately put in a large number of wells and have given up canal irrigation. In such cases the tenants on well irrigation have not agreed to bear any interest and depreciation charges on the well or the persian wheel.

(c) *Jarala and Dorana Langana in Multan district.*—In Multan district there are several tracts where it is very difficult to keep tenants on purely chahi irrigation. In such tracts, therefore, the landowner gets only one-third share of the produce of wheat and leaves the tenant to use all the Kharif and the other Rabi crops for himself. In such cases, as the interest and the depreciation charges on the well are not debited to the cultivator's account, the costs of irrigation have been low. There are instances where zemindars have spotted sites of old abandoned wells and have cleared them for use. In such cases the cost of construction of the well is very low and hence its depreciation and interest charges are small. As the landlords in Multan district get very little return on their chahi lands it may be concluded that they would welcome the idea of tube-well irrigation because in that case they can realize full rents.

In calculating the costs of irrigation by open wells no account has been taken of the labour required for driving the bullocks and for

diverting water from one small field to another. If tube-well irrigation is introduced very little labour would be required to irrigate one acre of land. It is calculated that on an open well it takes approximately 24 hours to irrigate one acre of land. This means six men are required for driving the bullocks and diverting water from one field to another. In terms of money this will amount to Rs. 2-4-0. If annas 4 is taken as the cost of labour required for irrigating one acre when it is commanded by a tube-well the difference in the two costs is Rs. 2. If this is added to the cost of irrigation in the case of the open well the true costs will be much higher than are indicated in Table 46.

In general it may be stated that if the total area irrigated during the year is high the cost per acre irrigation is low. If the area irrigated is low the cost per acre irrigation is high.

3. *Depth of each irrigation.*—Figures for the depth of irrigations given are shown in the last column of Table 46. It will be seen that the depth varies from approximately one inch to about 4·2 inches. On a closer examination, out of the 51 wells examined 37 wells are such that the depth lies between 1·5 inches and 3·0 inches. There are five instances in which the depth is below 1·5 inches and nine cases where it exceeds three inches. In the majority of the cases high delta seems to be due to the relatively higher discharge from the well.

The Economics of open well and Tube-well Irrigation.—In Table 47 comparison has been made between the economics of open well irrigation and tube-well irrigation for the same estate. For open wells costs of irrigation as worked out in Table 46 have been used. For tube-well irrigation, each acre irrigation has been priced at Rs. 3. In the last column is shown the profit per acre on tube-well irrigation over and above the profit that the cultivators get if the estates were under open well irrigation. From this column it will be seen that, except for very few cases, the farmer gets a higher profit per acre on the introduction of tube-well irrigation than in the case of open well irrigation. In these isolated cases reasons for the relatively lower costs of irrigation by means of open wells have already been given. If, as is already mentioned, costs of labour employed for irrigation are taken into account these estates would also show higher profits in the case of tube-well irrigation.

In comparing the costs one point must be borne in mind and that is that the wells have already been constructed by the zemindars or their ancestors and they do exist. With the introduction of tube-wells the capital already invested in the construction of these wells cannot, therefore, be recovered by the cultivators and charges for interest and depreciation on the construction of wells would continue to be levied. On the contrary it must be remembered that a

large portion of the barani area of the estates would become chahi if tube-wells were constructed. In that case income from lands now barani will be as much if not higher than the existing chahi area. In the calculations given in this table the income on the introduction of tube-wells has been kept the same as in the case of the present chahi area. No credit has been taken for any of the present barani area being converted into irrigated area with the construction of tube-wells. The average rate of Rs. 3 per acre irrigation on tube-wells both for Kharif and Rabi is also on the high side.

(iii) *Measurement of Run-off in the Catchment Areas of Drains.*— In order to design a project for drainage, information is required to enable a decision to be made with respect to (a) the total capacity of the subsidiary and the main drains and (b) the density of the branch drains in that area.

The factors that influence the run-off in an area are :—

(1) The amount and the intensity of rainfall.
(2) Temperature and humidity.
(3) Topography.
(4) Character of the soil.
(5) Vegetation and cultivation.
(6) The depth of the water table.

For measuring the amount and the intensity of rainfall, Negretti and Zembro recording raingauges were provided which were installed in the catchment areas. The observers also lived in the area.

A detailed contour survey was carried out to determine the slope of the land and notes were made on the size of the bunds made and maintained by the zemindars.

A survey of each area was also made to record the agricultural operations, the crops sown and the irrigation applied to fields.

The depth of the water-table was measured every day in selected wells in the catchment area. For the measurement of run-off the whole of the water coming out of the catchment was passed through a channel. Discharge observations were taken immediately when the flow of water started in the channel and readings were taken every 15 minutes till the run-off ceased. From the discharge observations and the time taken for the water to pass through the channel the total volume of water received as run-off was calculated. Knowing the total area of the catchment, run-off was calculated in terms of cusecs per square mile. Two values for run-off per square mile have been given. One is the average run-off and the other is the maximum run-off per square mile during the period of rainfall. This is important, because in designing a project the figures for maximum run-off must also be taken into consideration. This is necessary because apart from additions to the water-table crops like maize are

very sensitive to overflooding and stagnant water. Experiments at Chakanwali showed that if water stagnates in maize fields for more than 12 hours the crop dies.

From the total volume of run-off received and the total rainfall recorded the percentage rainfall appearing as run-off has also been calculated.

Observations were made in three different portions of the Rechna Doah.

(a) *An area near Khambranwala on Palkhu Nala near the Upper Chenab Canal.*—The total area kept under observation at this site was approximately 70 acres. The main line Upper Chenab Canal runs at a distance of only 1,000 feet from the catchment area.

The normal monsoon rainfall for this area is approximately 22 inches. The tract is fairly intensively cultivated and the zemindars make very strong bunds to retain the whole of the rain. During the Kharif period when observations were made the crops sown were sugarcane, cotton, maize, rice, bajra, chari, gowara, san and tobacco.

Observations showed that even though the rainfall on any one day was as high as 3·6 inches and the intensity of rainfall as much as 0·72 inch per hour no run-off was received from the main catchment. One or two barani fields near the edge of the Palkhu Nala gave some run-off.

The water-table in the area is situated at a depth of approximately six feet from the natural surface. During the monsoon it rose by approximately 3·6 feet. The resnlts of run-off observations are given in Table 48 and the results of the measurements of rainfall and water-tables are shown in Fig. 89. From the results in Table 48 it may be concluded that if the area is intensively cultivated and the field bunds are well maintained by the zemindars very little water goes out of the fields.

The curves in Fig. 89, however, show some interesting results. A study of the curves shows that during the monsoon months the main factor determining the rise in the water-table is the rainfall. Neither irrigation from wells nor the vicinity of the main canal have such a profound influence as the rainfall. They also show that even though the Palkhu Nala which is the main drainage does not get any drainage from areas near Khambranwala, its discharge varies directly with the rainfall. This indicates that the main catchment of the Palkhu Nala is situated somewhere higher up and that seepage or run-off from the adjoining lands is a very minor addition to the Nala.

(b) An area, on the Sialkot-Pasrur Road, having almost the same rainfall as the Khambranwala area but a water-table situated at a depth of about 40 feet from the natural surface was selected. The total catchment area was approximately 100 acres. The soil of the

area is light and absorbs water readily. The field bunds in the catchment area were not very strong and were not well maintained. A part of the area was irrigated by well water but a very large part was cultivated barani. It was noticed that during rain, water broke through the bunds and drained into a depression where it was measured. The results for run-off per square mile are given in Table 48.

On 23rd July, 1938, rain started about 7 o'clock in the morning and in about five hours approximately 4 inches had fallen. Observations for run-off were still in progress when a heavy flood from the Aik Nallah entered the catchment area and made further observations impossible. An account of the flood and the damage done by it will be given later. The results of observations for run-off are given in Table 48. From these results it is clear that if the rainfall is heavy drainage should be such as to take 20·5 cusecs per square mile of the catchment area. If the drainage is incapable of doing that, water will accumulate and will cause a rise in the water-table. The monsoon during 1938 was very poor and yet the run-off was never less than 7 cusecs per square mile. The conclusion from this is that the capacity of the drains in this area should never be less than 7 cusecs per square mile of the catchment area.

On 23rd July, 1938, there was a heavy flood in the Aik Nallah and at about 7·0 P.M. the same day it overflowed its left bank at the following places :—

(1) Malu-Chhitu—a village about 5 miles from the catchment area.

(2) The crossing of the Sialkot-Narowal Railway.

(3) The crossing of the Sialkot-Pasrur Road.

The whole of the catchment area was flooded and was under water for a period of 24 hours. Three feet depth of water was passing through the dip on the road and this lasted for about 12 hours. Out of the standing crops charri, bajra, maize and cotton were all washed away. Sugarcane was not much damaged.

The opportunity was taken to trace the course of the flood and to see how the flood water distributed itself. It was found that large ponds existed in the villages. Flood water entered these ponds and distributed itself over the country instead of going into any drainage or into the river. A list of the villages flooded is given in Appendix 'A'. For the purpose of a drainage project therefore such floodings should also be taken into consideration.

The results for the well observations are given in Fig 90. These results confirm the conclusions arrived at for the Khambranwala area. It may, however, be stated that, whereas at the Khambranwala site the additions to the water-table may be direct and probably in the form of saturated flow, in the Sialkot area the additions to the

water-table can only take place through a medium of unsaturated soil. The curves presented in Figs. 89 and 90 have been more fully discussed under the heading "Investigation of Negative Pressure."

(c) *An area near Sagar on the Lower Chenab Canal.*—In this area the water-table is high but the monsoon rain seldom exceeds 14·0 inches. The land is less steep. The temperature is relatively high. The soil is light and the standard of cultivation is lower than in the cases of (a) and (b) above. The total catchment area selected for observation was 166·5 acres out of which approximately 100 acres are cultivated and the rest is all waste land. Observations showed that there was no run-off from the cultivated area. The results given in Table 48 therefore represent run-off from only the waste area but for the sake of a drainage project the run-off percentage, etc., have been calculated over the whole area. From these figures it will be seen that with the first rain the run-off was low but it went on increasing with the subsequent rains till on the 16th of August the average run-off per square mile reached a figure of 22 cusecs.

In the discussion under the Lower Raniwah Drain it has been pointed out that if the drain is not designed to take the full discharge received on account of seepage, the run-off from the catchment and the flood water from rivers and other drainages it spills over the country and ceases to function as a drain. The necessity of a properly designed drainage system therefore is very obvious and cannot be over emphasized.

(d) *The Effect of Negative Pressure on Well Measurements.*—In the Report of the Physics Section attention has been drawn to the effect of negative pressures on well readings and the large rise in well levels which can take place after rain due to the release of the negative pressure. While the subject is to be further investigated during the present year, Figs. 89 and 90 are of considerable interest in this connection. In Fig. 90 well levels are recorded, the water-table according to these well levels being approximately 41 feet deep in the middle of July. In this case the soil was light. In Fig. 89 the water-table is apparently much nearer the surface and the soil in this case is heavy.

Dealing first with Fig. 90 it would be seen that the rain on the 15th and 16th of July has caused the water-table to rise by 8·0 feet. The water-table appears to become steady at this level until the 23rd when a further sudden rise takes place following heavy rain. Rainfall after this date affects the water-table to a small extent only and not suddenly. It appears, therefore, that the rains on the 15th and 16th and on the 22nd to 24th have resulted in the complete release of the negative pressure and the rises do not represent actual additions to the water-table. The negative pressure having been released the rise due to the late rains represents true additions to the water-table due to this source.

In the case of Fig. 89 although the water-table is much nearer the surface the negative pressure released is much smaller than in the former case. It appears that the rains on the 22nd to 24th July result in a complete release of the negative pressure and that the further rains are responsible for slight additions to the water-table.

It appears necessary to attempt to explain the differences between the amounts of rise in the two cases. As a result of the examination of moisture contents of a large number of profiles it has been shown that if the water-table is at a depth of 6 feet from the surface then almost the whole depth of the soil is at the field moisture capacity. As the depth of water-table increases to 11 feet then a certain depth of soil crust at the surface can have a steep moisture gradient. The maximum depth of this zone of steep moisture gradient appears to be 5 feet. In the case of an 11 feet water-table the conditions would be the top 5 feet with the steep moisture gradient, the lower 6 feet being at field moisture capacity. In the case of a water-table 9 feet deep there would be a soil crust 3 feet deep with a steep moisture gradient. As it is only the films in the zone of the steep moisture gradient that create the negative pressure it follows that at the 9 feet water-table the negative pressure would only have to be released in a depth of 3 feet of soil. With a water-table situated at 40 feet from the natural surface the moisture gradient zone would be of a depth of 5 feet; the remainder of the profile being at field moisture capacity. The negative pressure to be released in this case would be that due to the 5 feet of the moisture gradient zone. It follows, therefore, that with a deeper water-table the negative pressure to be released would be greater than that with a shallow water-table. This appears to account for the differences in the two series of observations.

A further deduction that may be made from these observations is that for similar soil types the negative pressure that has to be released by rainfall is the same for all depths of water-table beyond 11 feet. This probably accounts for the apparent effects of the rainfall on a deep water-table. There will be differences in the amounts of negative pressures to be released for different soil types. In a clay soil the area of the films of water will be considerably greater than in a light soil and hence the negative pressures to be released in a clay soil will be greater than those in a light soil.

The release of this negative pressure may account for the apparent response of the water-table to rainfall in the case of an impermeable soil. If the well reading is registering pressure and not water level then it will only be necessary to release the negative pressure in the surface layers to obtain a response to rainfall in the well level. There would be no transfer of water from the surface to the water-table but only an increase in pressure being recorded. It is hoped to considerably elaborate these points in the next report as the result of the investigations now in progress.

APPENDIX 'A.'

SHOWING THE LIST OF VILLAGES OVER WHICH THE FLOOD WATER SPREAD ITSELF.

Serial No.	Name of village.	No. "Hadbast."	Serial No.	Name of village.	No. "Hadbast."
1	Malho Chitu ..	443	21	Chhauni Salrian ..	522
2	Rasulpur	446	22	Pragpur	521
3	Kotli Arain ..	502	23	Kotli	523
4	Dasganwali. ..	501	24	Kotla	234
5	Mugran	503	25	Nawanpind ..	233
6	Raipur	510	26	Doburjee	237
7	Jodhewali	512	27	Jhanod	230
8	Chak Nawan ..	513	28	Chanun Moon ..	231
9	Gopalpur	509	29	Akbarabad ..	232
10	Kishnewali ..	511	30	Sadra Badra ..	217
11	Rukhana	439	31	Bhadal	219
12	Uggowali	448	32	Ghaborora ..	220
13	Pura Hiran.. ..	238	33	Ispur	145
14	Pindi Arain ..	239	34	Karyal	211
15	Doburjee	251	35	Mughlanwali ..	214
16	Hamza Ghose ..	236	36	Sayadanwali ..	213
17	Bhikhoshore ..	235	37	Daryabala ..	142
18	Keo	508	38	Kotli Amir Ali ..	212
19	Sandrana	507	39	Chak Baga ..	127
20	Gunna Khurd ..	515	40	Dhira Sandha ..	514
			41	Sattowali	527

APPENDIX "A."

SHOWING THE LIST OF VILLAGES OVER WHICH THE FLOOD WATER SPREAD ITSELF.

Serial No.	Name of village.	No. "Hadbast."	Serial No.	Name of village.	No. "Hadbast."
1	Malho Chita ..	443	21	[illegible] .	222
2	Rasulpur	446	22	[illegible]	221
3	Kotli Arain ..	502	23	Kotli	223
4	Dasganwali.. ..	501	24	Kotla	234
5	Mugran	503	25	Nawabpind ..	233
6	Raipur	510	26	Dehurpur .	237
7	Jodhewali	512	27	Jharoli .. .	230
8	Chak Nawan ..	513	28	Chanan Mora ..	231
9	Gopalpur	509	29	Akbarabad ..	232
10	Kishnewali ..	511	30	Sadra Badra ..	217
11	Rukhana	434	31	Bhadal . ..	219
12	Uggowali	448	32	Ghatorora ..	220
13	Pura Hiran.. ..	238	33	Ispur . .	145
14	Pindi Arain ..	239	34	Karyal	211
15	Doburjee	251	35	Mughlanwali ..	214
16	Hamza Ghose ..	236	36	Sayadanwali ..	213
17	Bhikhoshore ..	235	37	Daryabala ..	142
18	Keo	508	38	Kotli Amir Ali ..	212
19	Sandrana	507	39	Chak Baga ..	127
20	Gunna Khurd ..	515	40	Dhira Sandha ..	514
			41	Sattowali	527

TABLE 30.

SHOWING THE VILLAGES AFFECTED BY 'THUR' AS REVEALED BY THE SPECIAL GIRDAWRI CARRIED OUT IN DECEMBER, 1938.

No.	Name of village and district	Depth to water-table in feet.	Conditions regarding Thur.
1	Talab (Chiniot, Jhang)	9·0	Thur appearing.
2	Chak 570 (Jaranwala, Lyallpur) ..	10·0	Do.
3	Mahranwala, Chak 61-G. B. (Jaranwala, Lyallpur).	12·0	Do.
4	Chak 559-G. B. (Jaranwala, Lyallpur) ..	12·5	Do.
5	Chak 560 G. B. (Jaranwala, Lyallpur) ..	14·0	Do.
6	Sarab Kalan and Naurang Di Jhugian (Nankana Sahib, Sheikhupura)	15·0	Do.
7	Chak 126-G. B. (Jaranwala, Lyallpur) ..	16·0	Do.
8	Kotla Sant Singh Wala, Chak 43-R. B. (Sheikhupura).	18·0	Do.
9	Chak 5 (Sheikhupura)	20·0	Do.
10	Chak 11-G. B., Masanda and Lalke (Sheikhupura).	20·5	Do.
11	Karyal, Chak 17-G. B. (Sheikhupura) ..	21·0	..
12	Chak 370-G. B. (Sheikhupura)	21·0	No Thur at the surface yet. Zone of accumulation of salts below the surface.
13	Chak 126-J. B., Kokrian Da Chak (Chiniot, Jhang).	23·5	Thur appearing.
14	Chak 187, Baloana Jhumra (Lyallpur) ..	23·5	
15	Chak 41, Marar Khurd (Sheikhupura) ..	23·5	Thur appearing.
16	Chak 110, Babewala (Lyallpur)	24·5	
16(a)	Kariwala, Chak 49 R. B. (Sheikhupura) ..	25·6	
17	Raipur, Chak 638-G. B. (Jaranwala, Lyallpur)	26·0	Thur appearing.
18	Chak 102-G. B. (Jaranwala, Lyallpur) ..	26·6	Do.
19	Chak 84-R. B. (Sheikhupura)	27·0	
20	Chak 103-G. B (Jaranwala, Lyallpur) ..	30·0	Thur appearing.
21	Chak Gerri 189 R. B. (Jaranwala, Lyallpur)	35·0	Do.
22	Khurarianwala, Chak 266-R. B. (Jaranwala, Lyallpur).	37·0	Do.
23	Phulaiwala, Chak 103-R. B. (Jaranwala, Lyallpur).	40·0	"

TABLE 31.

SHOWING THE RESULTS OF ANALYSIS OF SOILS FROM BLOCKS A AND B AT BENALA, DISTRICT MONTGOMERY.

Description of sample.	Block A, Sq. 24, Field 25.		Block B, Sq. 67, Field 20.	
	Total solids per cent	pH.	Total solids per cent.	pH.
1st 6"	0·41	8·79	3·85	8·48
2nd 6"	0·47	8·00	1·40	8·73
2nd ft.	0·15	8·60	1·070	8·78
3rd ft.	0·12	8·65	1·40	8·73
4th ft.	0·22	8·24	2·36	8·79
5th ft.	0·13	8·97	2·70	8·65
6th ft.	0·09	8·07	2·05	8·62
7th ft.	0·10	9·71	3·32	8·66
8th ft.	..	..	1·81	8·73
9th ft.	..	..	0·59	8·80
10th ft.	..	..	2·14	8·97
11th ft.	..	..	0·37	8·83
12th ft.	..	..	0·36	8·53
13th ft.	..	..	0·23	8·24
14th ft.	..	..	0·17	9·20
15th ft.	..	..	0·20	9·14
16th ft.	..	..	0·15	9·30
17th ft.	..	..	0·17	9·65

TABLE 30.

SHOWING THE VILLAGES AFFECTED BY 'THUR' AS REVEALED BY THE SPECIAL GIRDAWRI CARRIED OUT IN DECEMBER, 1938.

No.	Name of village and district	Depth to water-table in feet.	Conditions regarding Thur.
1	Talab (Chiniot, Jhang) ..	9·0	Thur appearing.
2	Chak 570 (Jaranwala, Lyallpur) ..	10·0	Do.
3	Mahranwala, Chak 61-G. B. (Jaranwala, Lyallpur).	12·0	Do.
4	Chak 559-G. B. (Jaranwala, Lyallpur) ..	12·5	Do.
5	Chak 560 G. B (Jaranwala, Lyallpur) ..	14·0	Do.
6	Sarab Kalan and Naurang Di Jhugian (Nankana Sahib, Sheikhupura)	15·0	Do.
7	Chak 126-G. B. (Jaranwala, Lyallpur) .	16·0	Do.
8	Kotla Sant Singh Wala, Chak 43-R B (Sheikhupura).	18·0	Do.
9	Chak 5 (Sheikhupura) ..	20·0	Do.
10	Chak 11-G. B., Masanda and Lalke (Sheikhupura).	20·5	Do.
11	Karyal, Chak 17-G B (Sheikhupura) ..	21·0	..
12	Chak 370-G B. (Sheikhupura)	21·0	No Thur at the surface yet. Zone of accumulation of salts below the surface.
13	Chak 126-J B, Kokrian Da Chak (Chiniot, Jhang).	23·5	Thur appearing.
14	Chak 187, Balosna Jhumra (Lyallpur) ..	23·5	
15	Chak 41, Marar Khurd (Sheikhupura) ..	23·5	Thur appearing.
16	Chak 110, Balewala (Lyallpur)	24·5	
16(a)	Kariwala, Chak 49 R. B. (Sheikhupura) ..	25·5	
17	Raipur, Chak 638-G. B (Jaranwala, Lyallpur)	26·0	Thur appearing.
18	Chak 102-G B. (Jaranwala, Lyallpur) .	26·5	Do.
19	Chak 84-R B. (Sheikhupura)	27·0	
20	Chak 103-G B (Jaranwala, Lyallpur) ..	30·0	Thur appearing.
21	Chak Gerri 189 R. B. (Jaranwala, Lyallpur)	35·0	Do.
22	Khurarianwala, Chak 206-R. B. (Jaranwala, Lyallpur)	37·0	Do.
23	Phulaiwala, Chak 103-R. B. (Jaranwala, Lyallpur).	40·0	Do.

TABLE 31.

SHOWING THE RESULTS OF ANALYSIS OF SOILS FROM BLOCKS A AND B AT RENALA, DISTRICT MONTGOMERY.

Description of sample.	Block A, Sq. 26, Field 23.		Block B, Sq. 57, Field 20.	
	Total solids per cent	pH.	Total solids per cent.	pH.
.. ..	0·41	8·79	3·85	8·48
.. ..	0·47	8·00	1·40	8·73
.. ..	0·15	8·69	1·070	8·78
.. ..	0·12	8·65	1·40	8·73
.. ..	0·22	8·24	2·36	8·79
.. ..	0·13	8·97	2·70	8·65
.. ..	0·09	8·67	2·05	8·62
.. ..	0·10	9·71	3·32	8·66
.. ..	..	..	1·81	8·73
.. ..	..	..	0·59	8·60
.. ..	..	..	2·14	8·97
.. ..	..	..	0·37	8·83
.. ..	..	..	0·36	8·53
.. ..	..	..	0·23	8·24
.. ..	..	..	0·17	9·20
.. ..	..	..	0·20	9·14
.. ..	..	..	0·16	9·30
.. ..	..	..	0·17	9·65

TABLE 32.

SHOWING RESULTS OF ANALYSIS OF A FIELD AT RENALA BEFORE AND AFTER ONE RICE CROP, RABI, 1938-39.

Description of sample	Before starting reclamation.		After one rice crop now under Berseem.	
	Percentage of total salt.	pH.	Percentage of total salt.	pH.
0—6"	0·41	8·79	0·04	8·08
6"—12"	0·47	8·00	0·04	8·17
1'—2'	0·15	8·89	0·07	8·25
2'—3'	0·12	8·65	0·08	8·28
3'—4'	0·22	8·24	0·06	8·40
4'—5'	0·13	8·07	0·07	8·43
5'—6'	0·09	8·67	0·04	8·33
6'—7'	0·10	8·71	0·05	8·31

STATEMENT 33.

SHOWING SALT CONTENT OF FIELDS UNDER RECLAMATION AT 97/2 L, LOWER BARI DOAB CANAL AFTER ONE RICE CROP.

Depth of sample.	Sq. 48 / 19 / B	Sq. 48 / 17 / B	Sq. 48 / 17 / A	Sq. 48 / 14 / B	Sq. 48 / 11 / B	Sq. 49 / 2 / B	Sq. 49 / 10 / B
0"—6"	0·09	0·21	0·13	0·19	0·11	0·16	0·21
6"—12"	0·09	0·10	0·07	0·14	0·08	0·14	0·34
1'—2'	0·08	0·14	0·14	0·08	0·27	0·31	0·30
2'—3'	0·14	0·19	1·43	0·15	0·13	0·24	0·40
3'—4'	0·17	1·14	1·31	0·02	0·27	0·27	0·38
4'—5'	0·21	0·02	1·15	1·02	0·27	0 50	0·25
5'—6'	0·10	0·20	1·04	0·02	1·14	0·66	1·48
6'—7'	0·19	0·42	0·02	..	0·66	0·85	1·80
7'—8'	0·24	0·13	0·01	0·25	1·03	1·36	2·40
8'—9'	0·29	0·27	0·70	0·85	0·64	2·01	2·44
9'—10'	0·17	0·46	0·32	0·29	0·89	1·63	1·42
10'—11'	1·06	0·22	0·31	0·32	1·56	1·62	1·76
11'—12'	1·51	0·44	0·21	0·69	2·23	2·50	1·40
12'—13'	1·20	0·21	0·29	0·42	1·42	2·48	1·69
13'—14'	0·61	0 21	0·49	0·91	0·61	2·08	2·63
14'—15'	0·81	0·21	0·28	0 59	1·11	1·89	1·03
15'—16'	0·75	0·20	0·24	1·23	0·57	1·71	2·85
16'—17'	0·54	0 26	0·47	1·69	0·98	1·60	3·46
17'—18'	..	0·27	0·69	2·78	0·43	1·68	2·65

Indicates the depth to which the salts have been removed into the soil profile.

TABLE 34.

SHOWING THE RESULTS OF THE ANALYSES OF SOILS FROM CHAK No. 97/9-L.

Site.	Depth.	Percentage of total salt.	pH.
Chak No. 97/9-L, Killa No. 43/2	1st 6"	1·22	9·50
	2nd 6"	1·33	9·33
	2nd ft.	1·30	9·40
	3rd ft.	1·11	9·36
	4th ft.	1·01	9·27
	5th ft.	0·87	9·30
	6th ft.	0·86	9·36
	7th ft.	0·99	9·27
	8th ft.	1·89	9·22
	9th ft.	2·00	8·96
	10th ft.	1·92	9·22
	11th ft.	2·56	9·27
	12th ft.	2·27	9·08
	13th ft.	2·27	9·10
	14th ft.	0·70	9·53
	15th ft.	0·60	9·57
	16th ft.	0·52	9·62
	17th ft.	0·52	9·72
	18th ft.	0·68	9·76
	19th ft.	1·78	9·57
	20th ft.	1·86	9·54
	21st ft.	1·22	9·74
	22nd ft.	0·84	9·76
	23rd ft.	0·80	9·62
	24th ft.	0·40	9·60
	25th ft.	0·29	9·66
	26th ft.	0·22	9·77
	27th ft.	0·21	9·64
	28th ft.	0·18	9·45
	29th ft.	0·18	9·50
	30th ft.	0·15	9·14
	31st ft.	0·10	9·16
	32nd ft.	0·07	9·61
	33rd ft.	0·02	9·52
	34th ft.	0·07	9·57
	35th ft.	0·08	9·40
	36th ft.	0·08	9·48
	37th ft.	0·08	9·21
	38th ft.	0·08	9·45
	39th ft.	0·15	9·82
	40th ft.	0·10	9·92
	41st ft.	0·08	9·77
	42nd ft.	0·09	9·70
	43rd ft.	0·07	9·62
	44th ft.	0·08	9·74

TABLE 35.

SHOWING THE RESULTS OF THE ANALYSES OF SOILS FROM CHAK 11/4-L.

Description of the soil.	Depth.	Percentage of total salt.	pH.
Sample from square No. 80, Killa 13 of Chak 11/4-L.	1st ft.	1·21	8·87
	2nd ft.	1·01	8·92
	3rd ft.	1·84	8·52
	4th ft.	1·65	8·56
	5th ft.	1·54	8·56
	6th ft.	1·23	8·67
	7th ft.	1·10	8·75
	8th ft.	1·37	8·58
	9th ft.	0·72	8·91
	10th ft.	0·86	8·90
	11th ft.	1·00	8·89
	12th ft.	0·99	8·74
	13th ft.	1·90	8·32
	14th ft.	2·00	8·36
	15th ft.	2·46	8·31
	16th ft.	2·43	8·51
	17th ft.	1·47	8·70
	18th ft.	0·59	9·36
	19th ft.	0·67	9·17
	20th ft.	0 91	8·92
	21st ft	1 06	8·89
	22nd ft.	0·29	8·77
	23rd ft.	0·23	8·23
	24th ft.	0·26	8·52
	25th ft.	0·24	8·54
	26th ft.	0·17	8·60
	27th ft.	0·21	8·67
	28th ft.	0·20	8·76
	29th ft.	0·19	8·75
	30th ft.	0·07	8·65

TABLE 36.

SHOWING THE RESULTS OF ANALYSES OF SOILS FROM CHAK 188-N.B. SEVEN YEARS AFTER RECLAMATION AND THE CULTIVATION OF LAND ON NORMAL WATER SUPPLY.

Description of sample.	pH.	Total solids.
1st 6"	7·89	0·11
2nd 6"	8·00	0·07
2nd ft.	8·12	0·07
3rd ft.	8·22	0·08
4th ft.	8·15	0·09
5th ft.	8·46	0·08
6th ft.	8·38	0·12
7th ft.	8·24	0·08
8th ft.	8·18	0·11
9th ft.	8·40	0·06
10th ft.	8·58	0·06

TABLE 37.

SHOWING RESULTS OF ANALYSES OF SOILS FROM THE ABANDONED CHAKANWALI RECLAMATION FARM.

Description of sample.	Depth.	Total soluble salts December, 1938.	pH December 1938.
A/1 Sub-plot 19, Field No. 3 ..	0—7"	0·10	8·20
Ditto ..	7"—11"	0·08	8·01
Ditto ..	11"—29"	0·06	7·86
Ditto ..	29"—36"	0·07	7·69
A/1 Sub-plot 27, Field No. 1 ..	0—5"	0·29	8·78
Ditto ..	5"—15"	0·11	8·49
Ditto ..	15"—24"	0 09	7·67
Ditto ..	24"—30"	0·01	7·88
C/1 Sub-plot 17, Field No. 1 ..	0"—3"	0·39	9·72
Ditto ..	3"—7"	0·13	9·48
Ditto ..	7"—18"	0·12	9·18
Ditto ..	18"—37"	0·09	8·92
G/1 Sub-plot 10, Field No. 1 ..	0—7"	0·05	7·98
Ditto ..	7"—16"	0·04	8·18
Ditto ..	16"—22"	0·05	8·02
Ditto ..	22"—33½"	0·02	8·11
H/1 Sub-plot 19, Field No. 1 ..	0—5"	0·09	7·16
Ditto	5"—10"	0·11	7·75
Ditto ..	10"—21"	0·14	8·02
Ditto ..	21"—29"	0·15	8·46
Ditto ..	29"—35"	0·15	8·55
H/1 Sub-plot 19, Field No 4 ..	0—5"	0·16	8·21
Ditto ..	5"—9"	0·18	8 78
Ditto ..	9"—15"	0·19	8·78
Ditto .	15"—31"	0·19	8·58
S. Sob-plot 1 ..	0—6"	0·10	7·17
Ditto ..	6"—12"	0·10	7·05
Ditto ..	1'—2'	0·09	7·89
Q. Sob-plot 9, Field No. 1 ..	0—4"	0·08	7·71
Ditto	4"—8"	0·12	7·88
Ditto ..	8"—17"	0·09	7·68
Ditto ..	17"—25"	0·07	7·18
L. Sub-plot 10, Field No. 1 ..	0—4"	0·07	7·80
Ditto ..	4"—9"	0·10	7·80
Ditto ..	9"—17"	0·11	7·26
Ditto ..	17"—21"	0·11	7·10

TABLE 38.

SHOWING THE INTERPRETATION OF AERIAL PHOTOGRAPH (B).

Serial No.	Village.	Total area.		As interpreted from the photograph taken in January, 1937.					
				Thur.		Patchy.		Culturable.	
		K.	M.	K.	M.	K.	M.	K.	M.
1	Bahariānwala ..	5,712	5	1,738	9	07	7	3,876	9
2	Jaita ..	6,078	16	1,692	13	117	15	4,268	8
3	Kanungo ..	2,385	1	891	8	16	0	1,477	13
4	Badomurado ..	6,370	16	2,436	6	33	6	3,901	4
5	Q. Sahib Singh ..	4,280	1	1,389	2	406	6	2,484	13
6	Kanianwala ..	5,263	15	3,704	6	54	13	1,504	16
7	Chak Sethian ..	2,604	10	1,061	4	8	0	1,435	6
8	Pirkot .	6,199	11	1,566	17	158	2	4,474	12
9	Tibli Harya ..	2,825	15	1,094	8	..		1,731	7
10	Sahooke Malian ..	18,299	4	9,777	2	107	16	8,414	6
11	Chichoke Malian ..	228	0	75	6	6	17	145	18
12	Bhattal ..	243	19	87	11	10	0	146	8
13	Jiwanpura Kalan ..	487	0	115	11	10	16	360	13
14	Aya ..	3,950	8	1,285	0	17	16	2,647	12
15	Murade Khurd ..	3,454	7	1,316	4	..		2,139	3
	Total area in acres ..	8,575	0	3,629	0	130	0	4,876	0

TABLE 39.

SHOWING TRUE AREAS ACCORDING TO THE INTERPRETATION OF THE AERIAL PHOTOGRAPH AND ACCORDING TO THE PATWARI'S GIRDAWARI.

Name of village.	From interpretation of photograph taken in January, 1937.		As actually checked in fields in January, 1939.		Patwari's figures for Rabi, 1937.		Patwari's figures for Kharif, 1938.	
	K.	M.	K.	M.	K.	M.	K.	M.
Bahrianwala	276	11	215	9	107	0	171	3
Jaita	168	5	179	5	88	15	96	11
Killa Sahib Singh ..	242	5	237	9	192	16	245	18
Kanianwala	476	8	473	2	126	19	322	2
Kanoongoi	143	2	115	14	34	7	92	18
Badomurade	865	7	631	4	114	9	717	13
Total ..	2,171	18	2,052	3	664	15	1,646	5
Total in acres ..	271·50		256·50		83·12		205·75	

TABLE 40.

RESULTS OF WATER ANALYSES FOR MAIN WAN DRAIN TAIL AT R. D. 37,500.

Date of sampling.	Discharge in cusecs.	Results of Analyses. pH.	Conductivity.	Total salts
4th January, 1935 ..	20·00	7·79	600	41·30
14th February, 1935 ..	30·00	7·61	..	58·00
16th March, 1935 ..	25·00	7·52	635	41·50
16th April, 1935 ..	32·00	7·40	560	41·00
..	..	7·75	565	43 50
6th June, 1935 ..	11·00	8·18	525	34·30
7th July, 1935	11·00	7·79	450	35·00
..	..	8 20	490	40·40
5th September, 1935 ..	20 00	7·93	745	55·50
4th October, 1935	13·00	7·93	570	38·80
5th November, 1935 ..	13·00	7·74	550	35·70
3rd December, 1935 ..	15·00	8·03	640	48·30
Average ..	..	7·83	575·45	43·05
5th January, 1936 ..	23·00	7·98	900	63·70
2nd February, 1936 ..	18·00	8·17	650	46·20
8th March, 1936	31·00	8·12	670	48·30
3rd April, 1936 ..	21·00	7·62	550	39·20
4th May, 1936 ..	13·00	7·83	525	37·00
3rd June, 1936	12·00	7·40	500	36·00
16th July, 1936	31·00	8·31	750	61·20
7th August, 1936	16·00	8·42	550	41·00
3rd September, 1936 ..	20·00	7·09	600	32·50
2nd October, 1936	21·00	7·70	675	45·80
3rd November, 1936	17·00	7·90	575	41·60
7th December, 1936 ..	19·00	7·93	625	45·20
Average ..	..	7·87	630·83	44·87

TABLE 40—concld.

Date of sampling.	Discharge in cusecs.	Results of Analyses.		
		pH.	Conductivity.	Total salts.
3rd January, 1937	25·00	8·10	600	43·20
2nd February, 1937	23·00	7·91	575	41·60
11th March, 1937	26·00	7·60	670	45·00
17th April, 1937	28·00	7·66	610	42·20
3rd May, 1937	18·00	7·50	560	38·50
3rd June, 1937	12·00	8·00	550	31·40
7th July, 1937	16·00	7·84	950	63·00
6th August, 1937	41·00	7·30	675	48·00
4th September, 1937 ..	10·00	7·31	690	49·30
3rd October, 1937	11·00	7·70	620	40·90
7th November, 1937	14·00	7·21	710	50·50
9th December, 1937 ..	17·00	..	..	..
Average ..	..	7·68	635·45	43·00

TABLE 41.

RESULTS OF WATER ANALYSES FOR MONA DRAIN, R. D. 327,500.

Date of sampling.	Discharge in cusecs.	Results of Analyses.		
		pH.	Conductivity.	Total solids.
12th May, 1932 .. .	9·20	8·38	950	71·20
4th October, 1932	15·20	8·29	1,070	77·20
Average ..	12·20′	8·33′	1,010·00′	74·20′
5th March, 1933	11·03	8·30	1,060	80·40
4th May, 1933 .. .	10·40	8·18	1,550	99·80
6th June, 1933 .. .	11·83	7·92	1,170	69·80
5th July, 1933	23·84	8·05	850	61·00
8th August, 1933	48·20	7·80	575	45·00
24th September, 1933 .	226·30	7·70	800	62·30
12th October, 1933 ..	67 32	7·84	1,080	75·20
4th November, 1933 . ..	.	8·06	1,100	79·50
3rd December, 1933	30·42	8·15	1,100	73·80
Average ..	52·49′	8·01′	1,031 06′	71·93′
5th January, 1934 . ..	33 21	8·23	920	81·70
3rd February, 1934 . ..	30·04	8·04	1,080	79·00
5th March, 1934 . ..	29 43	8·49	1,050	72·30
14th May, 1934	.	8·03	1,300	91·60
15th June, 1934	.	8·00	1,150	82·80
15th July, 1934	..	8·14	650	44·31
15th August, 1934	..	7·18	900	82·30
13th September, 1934 ..	..	7·70	1,240	82·00
15th October, 1934	..	8·42	1,150	71·60
18th November, 1934 ..	..	8·19	1,100	80·30
4th December, 1934	..	7·18	1,100	76·40
Average ..	30·89′	7·97′	1,058·18′	76·79′

TABLE 41—CONTD.

Date of sampling.	Discharge in cusecs.	Results of Analyses. pH.	Conductivity.	Total solids.
23rd January, 1935	Not available	8.32	1,375	75·80
31st December, 1935 ..	Ditto	8·61	1,100	70·00
31st January, 1936	Ditto	8·51	1,100	73·40
29th February, 1936 ..	Ditto	8·50	1,200	82·70
29th April, 1936	Ditto	8·22	925	63·40
29th May, 1936	Ditto	8·15	1,050	74·00
29th June, 1936	Ditto	7·86	975	77·60
29th July, 1936	Ditto	8.16	1,000	70·60
31st August, 1936	Ditto	8.06	1,100	78·20
28th September, 1936 ..	Ditto	8.21	1,225	81·25
29th October, 1936	Ditto	8.64	1,130	75·60
29th November, 1936 ..	Ditto	8.40	1,050	69·40
30th December, 1936 ..	Ditto	8.72	1,000	68·60
Average ..	..	8.32'	1,063.64'	73·88'
30th January, 1937 ..	Not available	8.60	975	70·90
28th February, 1937 ..	Ditto	8.39	1,150	87·00
29th March, 1937	Ditto	7.86	950	62·00
30th April, 1937	24·17	7.60	1,100	75·10
29th May, 1937	33·90	8.12	1,700	215·00
30th June, 1937	24·50	8.28	1,000	72·80
31st July, 1937	107·52	7 50	1,200	86·40
29th August, 1937 .. .	25·87	7.66	1,100	80·20
30th September, 1937 ..	21·64	7.60	2,800	198·00
28th October, 1937	18·56	8.10	975	72·00
30th November, 1937 ..	15·39	8.20	1,000	66·40
30th December, 1937 ..	29·17	7.92	1,000	71·40
Average ..	33·41'	7.99'	1,245.83'	96·43'

TABLE 41—concld.

Date of sampling.	Discharge in cusecs.	Results of Analyses.		
		pH.	Conductivity.	Total solids.
..	24·72	8·28	1,100	74·20
..	16·61	8·62	1,000	69·40
31st March, 1938	32·78	8·22	900	68·40
28th April, 1938	14·58	7·70	950	65·30
31st May, 1938	30·61	8·14	700	55·00
30th June, 1938	31·44	8·28	1,000	81·00
30th July, 1938 .. .	32·63	7·58	500	37·60
29th August, 1938 . ..	31·88	7·93	1,175	82·00
30th September, 1938 ..	20·25	7·31	1,300	96·20
30th October, 1938	22·69	7·72	900	69·40
Average ..	26·71	7·98	952·50	69·85

TABLE 42.

RESULTS OF WATER ANALYSES FOR BHEK PUMPING STATION.

Date of sampling.	Discharge in cusecs.	Results of Analyses		
		pH.	Conductivity.	Total solids.
19th April, 1931	9·21	7·55	3,900	210·30
15th June, 1931	9·00	7·41	3,700	247·50
5th July, 1931	9·66	7·37	3,600	265·70
13th August, 1931	16·60	7·35	4,000	269·10
4th October, 1931	15·00	..	4,000	282·40
5th October, 1931	0·80	..	4,000	265·60
16th November, 1931 ..	10·50	7·62	4,300	299·00
Average ..	11·60	7·40	3,928.57	267·40
12th February, 1932 ..	8·5	7·66	4,500	313·00
24th March, 1932	9·0	7·17	4,500	330·80
25th April, 1932	8·0	7·48	4,750	330·80
4th June, 1932 . ..	9·0	7·34	4,700	318·80
15th July, 1932	8·0	6·88	4,750	334 40
29th September, 1932 ..	8·0	7·70	4,250	301·00
19th October, 1932 .	7·5	7·36	4,600	331·80
6th November, 1932 .	8·0	7·79	4,250	301·10
24th December, 1932 ..	10·0	7·37	4,500	326·00
Average .	8·44	7·43	4,533.33	322 19
17th January, 1933 .	8·0	7·47	4,400	313·50
13th February, 1933 ..	8·0	6·85	4,750	332 80
29th March, 1933	8·0	7·71	5,600	344·40
13th April, 1933 . ..	9·0	7·70	4,900	335·20
21st May, 1933	8·5	7·47	5,200	347·00
20th June, 1933	7·8	7·18	5,400	348 50
28th July, 1933	8·0	7·58	5,000	376·40
29th September, 1933 ..	9·0	7·24	4,000	301·40
28th October, 1933	9·0	7·22	4,700	317·50
29th November, 1933 ..	8.0	7·42	4,350	320·90
Average ..	8.33	7·41	4,830	333·76

TABLE 42—concld.

Date of sampling.	Discharge in cusecs.	Results of Analyses.		
		pH.	Conductivity.	Total solids.
13th January, 1934	14·0	7·65	4,000	329·50
9th February, 1931 ..	8·0	7·52	4,700	340·80
21st March, 1934	8·0	7·95	5,500	422·60
11th April, 1931	8·0	7·90	5,400	338·60
19th May, 1934	8·0	7·55	5,100	364·80
8th June, 1034	8·0	7·65	4,775	321·00
22nd July, 1934	8·0	7·53	4,400	368·60
30th August, 1934	8·0	6·89	3,000	347·20
23rd September, 1934 ..	8·0	7·88	5,200	355·20
18th October, 1934	8·0	7·71	4,700	322·80
5th November, 1934	8·0	7·74	5,000	367·20
6th December, 1934	8·0	7·50	..	..
Average ..	8·50	7·63	4,806.25	351·60
5th January, 1935	8·0	7·90	5,700	362·50
16th February, 1935 ..	8 0	7·33	..	343·50
11th March, 1935	8·0	..	..	..
..	8·0	7·59	5,000	330·80
..	8·0	7·60	5,150	338·50
22nd June, 1935	8·0	7·60	5,000	339·40
11th August, 1935	8·0	7·90	5,200	353·20
9th October, 1935	6·0	7·90	5,500	365·60
6th November, 1935 . ..	6·5	7 74	5,000	353·50
22nd December, 1935 ..	8·0	8·06	4,080	337·70
Average ..	7·65	7·74	5,078.75	348·19
5th February, 1936 ..	8·0	7·79	5,400	347·70
20th March, 1936	8·0	..	4,900	357·00
29th April, 1936	8·0	7·50	6,200	478·80
21st May, 1936	8·0	7·46	5,000	374·40
17th June, 1936	7·0	7·66	5,230	391·40

TABLE 43.

RESULTS OF WATER-ANALYSES FOR LOWER RANIWAH DRAIN R. D. 23,000.

Date of sampling.	Discharge in cusecs.	Results of Analyses.		
		pH.	Conductivity.	Total solids.
28th August, 1936	Not available	7·92	4,050	294·10
29th September, 1936 .	Ditto	7·94	4,000	260·20
29th November, 1936	Ditto	7·78	4,750	349·80
29th December, 1936	Ditto	8 32	5,000	358·70
Average .	..	7·99	4,450	315·70
29th January, 1937 . .	..	7·78	5,000	397·50
28th February, 1937 ..	..	7·66	4,700	392·00
29th March, 1937 . ..	..	7·60	5,900	467·00
29th April, 1937 . ..	4·6	7·64	7,000	473 20
24th May, 1937		7·41	4,000	295·00
29th June, 1937 . ..	..	7·64	7,500	524·20
26th July, 1937	38·8	6 94	3,400	237·40
25th August, 1937 . ..	6·6	7·02	10,500	731·60
21st September, 1937 .	4·18	6·58	9,000	670·20
20th October, 1937 .	3·40	7·02	9,000	642·20
25th November, 1937 .	2 83	7·49	8,000	560·00
10th December, 1937	5 20	6 74	3,750	263·70
Average ..	9·36	7·29	6,479·18	471·24
23rd December, 1937 .	4·97	7·18	8,000	561·80
25th January, 1938 ..	3 50	7·23	8,000	602·40
	7·22	7·25	8,000	592·70
25th March, 1938 .. .	6·38	7·71	8,000	613·20
25th April, 1938	4·75	7·48	8,750	665·20
25th May, 1938	3·70	7·38	8,000	659·00
Average ..	4·92	7·37	8,125	615·72

TABLE 44.

RESULTS OF WATER ANALYSES FOR VAOH NALLAH.

Date of sampling.	Discharge in cusecs.	Results of Analyses.		
		pH.	Conductivity.	Total solids.
15th April, 1932	..	7·60	275	21·00
15th May, 1932	..	7·83	280	20·20
22nd June, 1932	..	7·60	280	20·00
15th July, 1932	..	7·07	640	58·40
15th August, 1932	..	7·81	420	34·40
15th September, 1932 ..	..	7·40	340	23·40
15th October, 1932	..	8·40	280	20·40
15th November, 1932 ..	..	8·10	310	25·60
15th December, 1932	..	8·36	275	18·60
Average ..	..	7·91	347·78	26·03
15th January, 1933	..	8·20	490	37·00
15th February, 1933 ..	..	7·87	300	23·80
15th March, 1933	..	8·55	225	15·00
15th April, 1933	..	8·05	210	16·00
15th May, 1933	..	7·89	275	21·00
15th June, 1933	..	7·49	270	20·60
15th July, 1933	..	7·87	300	23·20
15th August, 1933	..	7·98	220	24·40
15th September, 1933 ..	..	7·47	315	33·20
14th October, 1933	..	7·53	320	22·80
15th November, 1933 ..	..	8·00	265	18·60
15th December, 1933 ..	..	7·80	280	20·30
Average ..	..	7·90	291·17	23·02

TABLE 44—concld.

RESULTS OF WATER ANALYSIS FOR VAGH NALLAH.

Date of sampling.	Discharge in cusecs.	Results of Analyses.		
		pH.	Conductivity.	Total solids
15th January, 1934	.	7·55	300	25·00
15th February, 1934	..	7·55	320	16·20
14th March, 1934	..	8·01	330	23·60
15th April, 1934		8 55	345	21·80
15th May, 1934	.	7·75	250	18·80
15th June, 1934	..	8 30	220	21·40
18th July, 1934	.	7·49	280	18 80
15th August, 1934	.	7 15	300	26·20
15th September, 1934 ..	.	7·70	315	10·40
15th October, 1934	..	7·78	340	22·00
15th November, 1934 ..	.	7·80	300	20 00
15th December, 1934 ..	..	7 88	280	17·60
Average ..	.	7 81	306·67	20·00
15th January, 1935 ..	..	7·90	310	20·80
15th February, 1935 ..		7 95	575	46·20
15th March, 1935 . ..	.	7 54	270	17·50
15th June, 1935 . ..	..	4 43	105	15 70
15th July, 1935	..	8 02	275	18·50
18th August, 1935 ..		7 67	375	26·00
15th September, 1935 ..	.	8 34	275	19 00
15th October, 1935 ..	.	7 73	260	19·20
15th November, 1935 ..	..	9 63	1,300	96·10
7th December, 1935 ..	.	8 03	280	21·60
15th December, 1935 ..	.	8 76	260	21·[illegible]
Average ..	..	7 82	337·73	[illegible]
15th January, 1936	..	7·72	280	[illegible]
15th February, 1936	..	7·92	310	[illegible]

TABLE 45.

RESULTS OF WATER ANALYSES FOR PUMPING STATIONS.

Date of sampling.	Discharge in cusecs.	Results of Analyses.		
		pH.	Conductivity.	Total solids.
Sadrana Pumping Station.				
13th August, 1932	..	8·39	2,650	203·00
12th September, 1932 ..	..	8·25	3,750	273·20
13th October, 1932	..	7·75	2,600	192·80
25th November, 1932 ..	..	7·63	2,250	170·20
18th December, 1932 ..	..	7 39	1,800	137·60
Average ..	..	7·88	2,010	195·30
22nd February, 1933 ..	..	7·87	1,900	141·00
16th March, 1933	..	7·05	2,700	185·40
17th April, 1933	..	8·09	2,100	150·20
13th May, 1933	..	8·21	2,250	163·60
12th June, 1933	..	8·21	2,400	173·10
20th July, 1933	..	7·50	10,500	910·40
12th August, 1933	..	7·80	6,000	452·60
13th September, 1933 ..	..	7·67	1,500	110·20
18th October, 1933	..	7·22	2,280	169·10
14th November, 1933 ..	..	7·23	2,800	214·50
13th December, 1933 ..	..	7·69	3,100	233·20
Average ..	..	7·77	3,411·82	264·49

TABLE 45.—contd.

Date of sampling		Discharge in cusecs	Results of Analysis.		
			pH.	Conductivity.	Total solids.
Sadrana Pumping Station—continued.					
13th January, 1934 ..	..	..	7·86	2,700	214·00
17th February, 1934	..	..	7·38	2,300	202·50
19th March, 1934 ..	..	..	7·09	3,400	271·80
17th April, 1934 ..	.	..	8·01	2,500	203·20
21st May, 1934 ..	..	..	8·06	2,400	160·60
15th June, 1934 ..	..	..	7·10	3,050	278·80
13th July, 1934 ..	..	.	7·71	2,250	171·20
14th August, 1934 ..	..	..	7·16	1,325	151·20
14th September, 1934	..	..	7·46	1,600	125·10
16th October, 1934 ..	..	..	7·96	2,750	205·90
13th November, 1934	..	.	7·29	2,500	206·90
12th December, 1934	..	.	7·12	1,075	155·80
Average	..	..	7·52	2,487.50	195·53
24th January, 1935 ..	..	.	7·64	2,750	..
1st March, 1935 ..	..	..	8·04	3,200	240·10
21st March, 1935 ..	..	..	7·48	3,500	249·70
22nd June, 1935 ..	..	.	8·13	2,800	164·40
24th July, 1935 ..	..	..	7 97	2,400	174·30
25th August, 1935 ..	.	..	7 46	2,300	122 50
19th September, 1935	..	..	7·54	1,750	161·10
19th October, 1935 ..	..	..	7·65	2,700	154·00
16th November, 1935	..	..	7·80	2,250	168·60
11th December, 1935	..	..	7·73	2,450	165·00
..		..	8·00	2,300	..
Average	..	..	7·78	2,581·82	177·73

TABLE 45—contd.

Date of sampling.		Discharge in cusecs.	Results of Analyses.		
			pH.	Conductivity.	Total solids.
Sadkana Pumping Station—*concluded*					
13th January, 1936 ..	..	..	8·06	2,350	162·70
13th February, 1936	..	..	8·06	2,200	137·50
Mafh Pumping Station					
13th August, 1932 ..	.	.	8·46	1,825	135·70
12th September, 1932	.	.	8·20	3,000	207·00
13th October, 1932 .	..	..	7·61	3,000	216·80
25th November, 1932	..	..	8 12	2,450	198·20
18th December, 1932	..	.	7·68	1,650	124·80
Average	..		8·01	2,565	194·50
23rd February, 1933	..	..	8·01	1,700	124·60
16th March, 1933 ..	..	..	7·90	2,000	159·60
17th April, 1933 ..	..	..	7·87	1,950	137·20
14th May, 1933 ..	..	..	8·11	2,300	158·20
13th June, 1933 ..	..	..	8·18	2,400	173·90
20th July, 1933 ..	..	..	7·00	4,000	314·00
12th August, 1933 ..	..	..	8·63	4,600	338·60
13th September, 1933	..	..	8·32	3,000	223·60
18th October, 1933 ..	..	..	7·22	2,300	172·00
14th November, 1933	..	..	7·52	2,600	201·60
13th December, 1933	..	....	7·69	2,800	203·00
Average	..	..	7·91	2,695·45	200·59

TABLE 45—contd.

Date of sampling	Discharge in cusecs.	Results of Analyses.		
		pH.	Conductivity.	Total solids.
Mahr Pumping Station—*continued.*				
13th January, 1934 ..	..	8·88	4,200	315·20
17th February, 1934		7·87	2,700	236·20
19th March, 1934 ..	..	7·66	3,500	284·50
17th April, 1934 ..		7·67	2,750	153·20
21st May, 1934 ..	..	8·10	2,600	173·00
15th June, 1934 ..		7·70	2,750	205·30
13th July, 1934 ..		7·56	2,000	132·00
14th August, 1934 ..		7·51	1,250	134·40
14th September, 1934	..	7·06	2,200	147·70
16th October, 1934 ..	..	7·88	2,600	179·00
13th November, 1934	..	7·26	2,500	177·70
12th December, 1934		7·26	2,200	160·80
Average	..	7·70	2,595·83	194·14
1st March, 1935 ..	.	8·22	3,300	234·00
21st March, 1935 ..	.	7·82	3,300	223·20
22nd June, 1935 ..	.	8·23	2,500	163·60
24th July, 1935 ..	.	8·59	2,900	172·80
25th August, 1935 ..	..	7·69	2,800	210·40
19th September, 1935	..	7·57	1,600	111·20
19th October, 1935 .	..	7·77	2,500	185·40
16th November, 1935	..	8·14	2,500	179·80
11th December, 1935	..	8·13	2,400	165·60
	..	8·29	2,000	163·00
Average	..	8·06	2,550	181·79

TABLE 45.—CONTD.

Date of sampling.	Discharge in cusecs.	Results of Analyses.		
		pH.	Conductivity.	Total solids.
Marh Pumping Station—*concluded*.				
13th January, 1936	..	8·32	2,575	181·30
13th February, 1930 ..	..	8·06	2,200	152·00
Jhang Branch Pumping Station at R. D. 80,250				
12th July, 1932	.	7·02	300	24·60
13th August, 1932	..	8·46	1,550	121·60
12th September, 1932 ..	..	7·75	540	30·40
13th October, 1932	..	7·68	230	17·60
25th November, 1932 ..	..	8·02	700	51·60
18th December, 1932 ..	.	7·63	400	32·00
Average ..	..	7·74	620	47·30
23rd February, 1933 ..	..	7·56	170	27·40
16th March, 1933	..	7·78	350	27·40
17th April, 1933 . ..	.	7·58	600	51·40
13th May, 1933 . ..	..	9·43	2,300	137·20
12th June, 1933	..	7·88	455	32·50
19th July, 1933 . ..	..	7·70	1,800	149.60
11th August, 1933	..	7·36	875	69·40
18th October, 1933 . ..	..	7·87	1,000	150·00
14th November, 1933 ..	..	7·73	750	52·60
15th December, 1933 ..	..	8·35	675	50·50
Average .	..	7·92	1,015·50	70·80

TABLE 45.—concld.

Date of sampling.	Discharge in cusecs.	Results of Analyses.		
		pH.	Conductivity.	Total solids.
Jhang Branch Pumping Station at R. D. 80,250—concluded.				
12th January, 1934	.	8·50	1,575	121·80
17th February, 1934	..	7·45	380	31·80
19th March, 1934 ..	.	7·17	260	17·20
17th April, 1934	.	7·04	318	18·90
21st May, 1934	.	7·90	400	26·60
15th June, 1934 . .	..	7·40	270	18·20
13th July, 1934	..	7·03	750	48·90
13th August, 1934		7·34	900	87·00
14th September, 1934 .		7·64	680	48·10
16th October, 1934	.	7·61	550	35·70
13th November, 1934	..	7·37	375	21·00
12th December, 1934	.	7·40	375	27 10
Average .	.	7·57	569·42	41·86
24th January, 1935 .. .	.	7·83	725	..
1st March, 1935 . .	.	8 12	1,780	128·50
21st March, 1935		7·58	825	55·40
.	..	7 83	275	15·70
22nd June, 1935	.	7 58	500	30 00
24th July, 1935	.	7·59	725	51 50
25th August, 1935	.	7·91	1,000	75 40
19th September, 1935	.	7·77	280	18·10
18th October, 1935 .		7·63	600	40·00
16th November, 1935 .		7 91	375	20·00
11th December, 1935 ..	..	7·90	600	46 53
Average ..	..	7·70	608·64	48 81
12th January, 1936	..	8·02	500	31·60
13th February, 1936 ..	..	8 27	800	38 20
[illegible] Pumping Station.				
12th January, 1942 ..	..	7·41	725	59·00

TABLE 46.

SHOWING THE COST OF ONE ACRE IRRIGATION BY OPEN WELLS IN DIFFERENT PARTS OF THE PUNJAB.

Name of District	Name of Village	Depth to water table	Discharge of the well in cusecs.	Average time taken to irrigate an acre in hours.	Total number of bullocks employed.	Total number of working days spent by bullocks.						Total cost of the maintenance of bullocks.
						Cultivation.	Working of Persian Wheel.	Cane crushing.	Running of bullock carts.	Miscellaneous.	Total number of working days.	
												Rs. A. P.
Jullundur ..	Dholi ..	33·6'	·11	24	4	62	151	19	.	8	273	330 11 0
	Nussi	32·0'	·08	22·5	4	49	130	3	..	8	190	215 0 9
	Karyana ..	18·1'	·09	29·0	4	90	92	..	.	10	182	311 3 3
	Bahauddinpur ..	25·0'	·10	19·0	4	101	35	.	..	10	149	300 11 6
	Dhopur ..	25·0'	·11	20·0	5	61	76	10	60	10	207	456 1 3
	Nakodar ..	47·1'	·11	27·2	4	77	181	5	..	10	273	249 4 0
	Silhuan	55·3'	·06	27·0	4	52	188	3	..	10	253	260 4 3
	Mehtpur ..	37·6'	·07	42·0	4	55	147	5	..	10	217	180 10 3
	Talwandi Bakhsha ..	28·6'	·12	26·0	4	51	183	10	..	10	254	205 3 0
	Lassuri ..	23·6'	·14	32·5	4	79	193	2	..	10	284	210 13 0
	Roorka ..	50·0'	·12	18·0	6	72	171	11	..	5	259	381 15 3
	Lasara ..	45·6'	·14	16·81	4	80	53	10	..	6	149	207 4 9

TABLE 46—CONTINUED.

SHOWING THE COST OF ONE ACRE IRRIGATION BY OPEN WELLS IN DIFFERENT PARTS OF THE PUNJAB.

Name of District.	Name of Village.	Share of upkeep debitable to the working of Persian Wheel	Cost of sinking a well.	Share held by the owner	Interest and depreciation on the well and the Persian Wheel for the share of the well	Total expenditure incurred on irrigation.	Total acre irrigation during the year	Cost per acre irrigation.	Depth of one irrigation in inches.
		Rs. A. P.	Rs		Rs. A. P.	Rs. A. P.		Rs. A. P.	
Jullundur ..	Dholo .	218 9 0	800	1	113 9 6	262 2 6	77·45	4 11 3	2·64
	Nussi ..	147 2 3	800	2	182 13 3	329 15 6	52·40	6 3 0	1·80
	Karyana .	140 3 3	400	1	17 14 6	187 11 9	25·52	7 5 9	2·64
	Bahauddinpur ..	70 10 3	1,600	1	205 6 0	276 0 3	11·65	18 13 6	1·90
	Dhopur .	107 7 3	1,200	1	103 1 3	330 9 6	31·14	9 10 9	2·20
	Nakodar ..	165 4 0	{ 1,200 1,300 }	{ 1/3 1/9 } =4/9	106 9 0	271 13 0	79·62	3 6 6	2·97
	Sidhwan ..	103 6 0	2,000	4/15	77 4 6	270 10 6	62·78	1 5 0	1·63
	Mehtpur ..	122 6 0	{ 1,250 800 500 }	{ 1/2 1/6 1 } =1.2/3	169 1 3	291 7 3	12·11	6 11 9	2·04
	Talwandi Bakheha ..	212 10 9	1,500	1,1/6	264 3 0	476 13 9	84·36	5 10 6	2·86
	Lassuri ..	143 4 3	900	{ 1/9 2/5 1/9 2/5 } =40/45	169 15 3	313 3 6	107·1	2 14 9	2·27
	Roorka ..	252 2 9	1,500	1	193 8 0	445 10 9	80·51	5 2 6	2·16
	Lasara ..	95 1 3	600	11/20	84 0 3	179 1 6	29·17	6 5 9	2·33

TABLE 46—CONTINUED.

SHOWING THE COST OF ONE ACRE IRRIGATION BY OPEN WELLS IN DIFFERENT PARTS OF THE PUNJAB.

Name of District.	Name of Village.	Depth to water table.	Discharge of the well in cusec.	Average time taken to irrigate an acre in hours.	Total number of bullocks employed.	Total number of working days spent by bullocks. Cultivation.	Working of Persian Wheel.	Cane crushing.	Running of bullock carts.	Miscellaneous.	Total number of working days.	Total cost of the maintenance of bullocks.
												Rs. A. P.
Jullundur—concld.	Phoralls ..	25·0′	·12	17·5	5	49	178	15	..	5	247	371 12 3
	Mukandpur ..	39·0′	·12	18·2	5	174	157	15	..	5	351	234 0 3
Hoshiarpur ..	Basi Ghulam Husain	4·4′	·10	18·5	7	52	31	6	30	10	129	308 0 0
	Kala Jhangar ..	39·0′	·10	19·5	2	70	35	2	..	10	117	103 10 3
	Dugri .	8·5′	·13	24·5	3	134	28	3	..	5	170	125 10 9
Gujranwala ..	Chak Jagna ..	15·6′	·15	25·0	4	85	138	..	.	10	233	204 2 0
	Chak Nizam ..	21·5′	·15	19 0	0	61	140	4	..	10	215	265 9 9
	Tarounja ..	17·0′	·12	19·7	6	47	140	5	..	10	202	218 0 6
	Chak Ramdas, Old ..	15·0′	·14	20·2	6	90	112	..	..	10	212	388 5 0
Sialkot ..	Lakhanpur ..	37·6′	·09	27·9	4	78	102	7	.	10	197	200 7 3
	Bharoke ..	28·6′	·04	53·5	4	113	23	2	..	10	148	180 15 9
	Gurhi ..	32·6′	·10	24·5	4	131	01	7	..	10	209	231 12 0

TABLE 46—*continued.*

SHOWING THE COST OF ONE ACRE I RIGATION BY OPEN WELLS IN DIFFERENT PARTS OF THE PUNJAB.

Name of District.	Name of Village.	Share of upkeep debitable to the working of Persian Wheel.	Cost of sinking a well.	Share held by the owner.	Interest and depreciation on the well and the Persian Wheel for the share of the well.	Total expenditure incurred on irrigation.	Total acre irrigation during the year.	Cost per acre irrigation.	Depth of one irrigation in inches.
		Rs. A. P.	Rs.		Rs. A. P.	Rs. A. P.		Rs. A. P.	
Jullundur—*concld*	Phoralla	207 14 6	600	1.1/2	114 0 0	412 7 6	91·33	4 6 3	2·10
	Mukandpur	104 10 9	1,000	1/3	69 4 6	173 15 3	77·88	2 3 0	2·17
Hoshiarpur ..	Basti Ghulam Husain	74 1 9	600	1	106 2 0	180 4 6	15·11	11 14 0	1·85
	Kala Jhangar ..	31 0 0	800	1/8 } 1/8 } =1/4	47 6 3	78 6 3	16·01	4 14 3	1·05
	Dugri ..	20 11 3	600	1/2	41 11 0	62 6 3	6·76	0 3 0	3·00
Gujranwala ..	Chak Jagna	120 14 3	600	1/2	64 3 6	185 1 0	66·21	2 12 0	3·75
	Chak Nizam ..	172 15 3	400	1/3	90 0 0	263 0 0	132·44	1 15 9	2·83
	Taraunya ..	151 1 6	400	1/4	20 3 0	171 4 6	107·57	1 9 6	2·37
	Chak Ramdas, Old	205 2 6	600	2/3	143 7 0	348 10 3	99·42	3 8 0	2·83
Sialkot ..	Lakhanpur	150 6 3	800	1/4 } 1/6 } =13/24 1/8 }	65 4 3	215 10 6	43·53	4 15 3	2·48
	Bharoke ..	28 2 0	720	1/6	22 6 0	50 8 0	5·13	0 13 6	2·30
	Gurbi	67 10 3	800	1/7	20 9 6	88 3 9	23·83	2 15 3	2·40

TABLE 46—CONTINUED.

SHOWING THE COST OF ONE ACRE IRRIGATION BY OPEN WELLS IN DIFFERENT PARTS OF THE PUNJAB.

Name of District.	Name of Village.	Depth to water table.	Discharge of the well in cusecs.	Average time taken to irrigate an acre in hours.	Total number of bullocks employed.	Total number of working days spent by bullocks. Cultivation.	Working of Persian Wheel.	Cane crushing.	Running of bullock carts.	Miscellaneous.	Total number of working days.	Total cost of the maintenance of bullocks. Rs. A. P.
Sialkot ..	Sodhreke ..	24·6′	·09	36·50	4	82	120	2	..	10	214	281 4 0
	Abdali	32·6′	·08	38·00	5	94	110	.	..	10	214	241 2 0
Gujrat ..	Gurali ..	10·6′	·10	19·96	4	80	108	1	..	10	199	273 2 9
	Pindi Hasna ..	17·0′	·09	25 00	4	118	55	1	..	6	180	209 3 3
	Fatehpur ..	9·6′	·08	19·15	4	77	39	8	.	10	154	141 5 9
	Chechian ..	11·6′	·11	29 17	4	98	106	..	..	10	214	300 2 0
Amritsar ..	Lola ..	20·0′	·19	17·22	4	79	117	3	..	10	209	293 1 0
	Ramdev Wali ..	20·0′	·13	21 00	5	70	106	4	..	10	190	240 2 6
	Hamidpur ..	10·6′	·17	16·25	4	65	51	..	.	10	129	292 8 0
	Rampur ..	16·0′	·17	21 25	5	103	163	.	..	10	276	297 3 9
	Sadhpur ..	18·6′	·18	23·75	4	77	81	3	..	10	171	221 7 0
Multan ..	Faridpur ..	32·0′	·06	24 00	6	25	162	..	..	10	197	345 13 0
	Khanpur ..	37·6′	·06	28·50	8	14	129	..	..	10	153	274 0 0

TABLE 46—continued.

SHOWING THE COST OF ONE ACRE IRRIGATION BY OPEN WELLS IN DIFFERENT PARTS OF THE PUNJAB.

Name of District.	Name of Village.	Share of upkeep debitable to the working of Persian Wheel.	Cost of sinking a well.	Share held by the owner.	Interest and depreciation on the well and the Persian Wheel for the share of the well.	Total expenditure incurred on irrigation.	Total acre irrigation during the year.	Cost per acre irrigation.	Depth of one irrigation in inches.
		Rs. A. P.	Rs.		Rs. A. P.	Rs. A. P.		Rs. A. P.	
Sialkot ..	Sodhreke ..	157 11 9	700	1/2	77 0 6	234 12 3	39·45	5 13 6	3·17
	Abdali .	123 15 0	600	1/3, 1/8 =11/24	37 12 6	191 12 0	34·76	5 7 6	3·00
Gujrat .	Gurali .	148 4 0	800	1	150 10 6	298 14 6	64·56	4 9 9	1·99
	Pindi Hasna	63 14 9	600, 1,000	1/8, 1/4 =3/8	64 13 3	128 12 0	26·45	4 13 0	1·49
	Fatehpur ..	54 2 9	300	1	83 7 6	137 10 0	35·14	3 14 9	1·66
	Chechian ..	146 10 6	1,000	1/9, 3/4 =31/36	154 14 3	301 8 9	43·35	7 0 0	3·20
Amritsar ..	Lola	158 7 3	600	5/16	45 11 6	204 2 0	71·14	2 14 0	3·27
	Ramdev Wali ..	139 0 0	500	5/18	27 0 9	166 0 9	60·92	2 11 6	2·73
	Hamidpur ..	122 7 0	600	1/4, 1/4, 1/2 =1	98 8 0	220 15 0	40·06	5 8 3	2·76
	Rampur ..	175 8 9	600	3/4	78 8 0	254 0 9	80·74	3 2 3	4·1
	Sadhpur ..	104 14 3	600	1/2, 1/24 =13/24	75 6 9	180 5 0	40 92	4 6 6	4·27
Multan ..	Faridpur ..	284 6 0	700	1	127 8 0	411 14 0	124·77	3 6 0	1·37
	Khanpur ..	231 5 3	400	Tenant.	22 8 0	253 13 3	67·94	3 11 0	4·83

TABLE 46—continued.

SHOWING THE COST OF ONE ACRE IRRIGATION BY OPEN WELLS IN DIFFERENT PARTS OF THE PUNJAB.

Name of District.	Name of Village	Depth to water table.	Discharge of the well in cusecs.	Average time taken to irrigate an acre in hours.	Total number of bullocks employed.	Total number of working days spent by bullocks.						Total cost of the maintenance of bullocks.
						Cultivation	Working of Persian Wheel.	Cane crushing.	Running of bullock carts.	Miscellaneous.	Total number of working days.	
												Rs. A. P.
Multan—concld.	Inaitpur ..	37·0'	·06	33·60	8	60	275	..	..	10	345	359 10 3
	Jarola ..	17·0'	·06	31·00	4	22	229	.	..	..	251	80 12 3
	Saraf Sallu ..	19·6'	·06	35·50	4	37	203	..	..	5	245	367 8 3
	Dorana Langana ..	16·6'	·09	20·25	5	99	166	..	..	10	275	131 4 6
	Nilkot ..	8·0'	·08	33·25	6	72	133	..	..	5	210	208 5 0
Ludhiana ..	Samrala ..	32·2'	·08	16·00	4	53	124	6	..	5	188	345 0 6
	Khanna Khurd ..	37·6'	·09	15·00	6	93	194	8	..	5	300	391 3 9
Gurgaon ..	Tauru ..	28·0'	·09	15·00	2	104	114	..	..	5	223	255 12 0
	Bassar Akbarpur ..	48·6'	·08	22·25	4	52	119	..	..	5	176	167 13 6
	Baboopur ..	18·0'	·07	17·00	3	163	51	..	..	5	219	162 7 0
	Chanse ..	30·0'	·07	19·00	4	81	24	..	..	5	110	116 7 9
	Pathrali ..	30·0'	·12	14·00	6	92	58	..	..	5	155	300 1 3
	Nagina ..	13·0'	·15	22·12	4	96	78	..	..	2	176	144 0 6
	Ter ..	22·0'	·12	17·00	4	93	43	..	..	5	141	134 11 3

TABLE 46 CONCLUDED.

SHOWING THE COST OF ONE ACRE IRRIGATION BY OPEN WELLS IN DIFFERENT PARTS OF THE PUNJAB.

Name of District.	Name of Village.	Share of upkeep debitable to the working of Persian Wheel	Cost of sinking a well.	Share held by the owner	Interest and depreciation on the well and the Persian Wheel for the share of the well.	Total expenditure incurred on irrigation.	Total acre irrigation during the year.	Cost per acre irrigation.	Depth of one irrigation in inches.
		Rs. A. P.	Rs		Rs. A. P.	Rs A. P.		Rs. A. P.	
Multan—contd.	*Inaltpur*	280 10 9	700	Tenant	13 0 0	299 10 0	106 49	2 13 0	1·74
	Jarola	81 14 3	700	1/2	90 14 0	172 12 3	89·69	1 15 3	2·01
	Saral Sidhu ..	304 8 3	500	1/2	61 5 9	355 14 0	69·59	5 3 0	2·14
	Dorana Langana	79 4 0	700	Tenant	6 12 0	86 0 0	99·29	0 14 0	1·42
	Nilkot	131 14 0	700	1	132 2 9	264 1 6	71·92	3 10 9	2·66
Ludhiana ..	Samrala	227 9 3	600	1, 63/4032	117 8 0	345 1 3	69·69	4 15 3	1·34
	Khanna Khurd	253 0 0	400	25/21	95 10 6	348 10 6	116 65	2 15 9	1·33
Gurgaon ..	Tauru	145 0 0	1,000	¼	74 2 6	219 11 6	60·63	3 10 0	1·71
	Bissar Akbarpur	113 7 9	1,000	1	136 11 0	250 2 9	41·37	6 0 9	1·42
	Baboopur	37 13 3	800	1	70 2 0	107 15 3	18 00	6 0 0	1·12
	Chanse	25 6 9	600	1/16 ¼	11 14 9	37 5 6	9·90	4 3 0	1·33
	Pathrali	112 4 6	1,000	1/16 1	122 4 8	234 9 0	21 81	9 7 3	1·73
	Nagina	64 1 3	700	1	41 12 0	103 13 3	19·50	5 9 3	3·31
	Ter	41 1 3	1,000	1,15	23 4 3	64 5 6	15 25	4 3 6	1·97

TABLE 47.

SHOWING THE ECONOMICS OF OPEN WELL IRRIGATION AND TUBE WELL IRRIGATION.

Name of District.	Name of Village.	Depth to water table.	Cost of one acre irrigation by open well.	Area of the Estate.			Total acre irrigation during the the year.
				Chahi.	Barani.	Total area in acres	
			Rs. a. p.	Acres	Acres.	Acres	Acres.
Jullundur ..	Dhole ..	33·6'	4 11 0	9·08	10·49	19·57	77·05
	Nussi ..	72·0'	6 5 6	7·99	4·68	12·67	52·00
	Karyana ..	18·1'	7 5 0	2·37	17·28	19·65	27·52
	Bahauddinpur .	25·0'	18 13 6	1·91	17·06	19·87	14·65
	Dhepur	25·0'	9 10 9	4·56	7·68	12·24	34·14
	Nakodar ..	47·1'	3 8 0	7·76	4·10	11·86	79·62
	Sidhwan ..	75·9'	4 5 0	6·87	8·98	15·85	62·78
	Mehtpur ..	37·6'	6 14 9	4·49	7·34	11·83	42·11
	Talwandi Bakhsha ..	28·6'	5 10 3	7·32	9·37	16·69	84·36
	Lassuri ..	23·6'	2 14 9	14·66	2·70	17·36	107·10
	Roorka ..	50·0'	5 2 6	8·84	1·76	10·60	86·54
	Lasara ..	45·6'	6 5 9	4·08	9·64	13·72	28·17
	Phoralla ..	25·0'	4 9 3	12·25	0·34	12·59	91.33

TABLE 47 —CONTINUED.

SHOWING THE ECONOMICS OF OPEN WELL IRRIGATION AND TUBE WELL IRRIGATION.

Name of District.	Name of Village	Total expenditure under open well irrigation.							
		Land Revenue.	Outside labour.	Upkeep of bullocks.	Int. and dep. on well and Persian Wheel.	Int. and dep. on implements.	Cost of seed.	Wages of Kamins.	Miscellaneous.
		Rs. A. P.	Rs. A. P.	Rs. A. P.	Rs. A. P.	Rs. A. P.	Rs. A. P.	Rs. A. P.	Rs. A. P.
Jullundur—*contd.*	Dhode	61 11 6	38 13 3	330 11 0	143 9 6	27 3 3	41 8 0	37 3 0	20 0 0
	Nussi	38 7 6	32 8 0	215 0 9	182 13 3	21 9 9	42 12 0	33 2 6	0 14 6
	Karyana	72 5 3	128 11 9	311 3 3	47 11 6	31 6 0	52 2 0	71 0 0	2 15 0
	Bahauddinpur	100 11 9	60 8 0	300 11 6	205 0 0	19 9 6	46 0 0	70 9 0	1 0 0
	Dhepur	47 0 0	13 12 0	450 1 3	103 1 3	14 6 0	40 12 0	37 1 0	1 15 6
	Nakodar	11 [illegible] 0	27 1 0	249 4 0	106 9 6	22 1 3	30 2 0	28 10 6	1 1 0
	Sidhwan	[illegible] [illegible] 9	10 4 0	260 4 3	77 1 0	14 11 3	58 7 0	32 15 6	1 8 0
	Mehtpur	11 8 6	68 8 0	180 10 3	169 1 7	37 2 6	37 10 3	41 5 3	21 0 0
	Tahranda Bakhsha	[illegible] 11 9	14 0 0	295 3 0	264 3 0	39 8 3	50 3 3	52 0 0	2 2 0
	Lasuri	17 9 0	4 0 0	210 13 0	169 15 3	31 9 9	54 11 0	44 0 0	1 0 3
	Rurka	56 3 6	31 2 0	381 15 3	193 8 0	19 1 3	44 13 3	36 4 0	2 4 0
	Lasara	11 1 6	8 13 0	267 4 9	81 0 3	40 15 6	27 12 0	38 2 3	1 6 6
	Phoralla	81 7 9	20 0 0	371 12 3	141 9 0	51 7 6	31 5 0	50 15 0	2 0 0

TABLE 47.—CONTINUED.

SHOWING THE ECONOMICS OF OPEN WELL IRRIGATION AND TUBE WELL IRRIGATION.

Name of District.	Name of Village.	Total Expenditure.	Total income in a normal year	Net saving under open well irrigation in a normal year	Total expenditure under tube well irrigation.	Net saving under Tube well irrigation in a normal year	Profit or loss on the introduction of tube well irrigation.	Profit or loss per acre.
		Rs. A. P.	Rs. A. P.	Rs. A. P.	Rs. A. P.	Rs. A. P.	Rs. A. P.	Rs. A. P.
Jullundur—contd.	Dhode ..	706 11 6	864 0 0	157 1 6	575 12 0	288 4 0	131 2 0	0 11 3
	Nussi ..	572 1 3	658 8 3	86 4 0	398 4 9	260 3 0	173 15 0	13 11 0
	Karyana ..	717 9 9	711 10 6	24 0 9	606 11 0	134 15 0	110 14 9	5 10 3
	Bahauddinpur ..	819 0 3	820 0 0	0 15 9	581 0 0	239 0 0	232 0 3	11 10 9
	Dhepur ..	894 3 0	1,090 0 0	285 13 0	575 10 0	514 5 6	228 8 6	18 10 0
	Nakodar ..	515 9 0	629 3 3	113 10 3	482 12 0	146 7 3	32 13 0	2 12 3
	Sidhwan ..	489 12 9	646 0 0	156 3 3	107 2 3	238 13 9	82 10 6	5 3 6
	Mehtpur ..	602 7 0	623 0 0	20 9 0	436 15 9	186 0 3	165 7 3	13 15 9
	Talwandi Bakhsha ..	774 5 3	853 0 0	78 10 9	550 7 6	302 8 0	223 13 9	13 6 6
	Lassuri ..	537 1 6	542 0 0	4 14 6	544 11 0	—2 14 0	—7 12 6	—0 7 3
	Roorka ..	765 6 0	930 0 0	164 0 3	579 12 0	350 4 0	185 10 9	17 8 3
	Lasara ..	509 7 9	656 0 0	146 8 3	415 6 3	240 9 9	94 1 6	6 13 9
	Phoralli ..	762 15 0	1,009 0 0	246 1 0	624 7 6	384 8 6	138 7 6	11 0 0

TABLE 47—CONTINUED.

SHOWING THE ECONOMICS OF THE OPEN WELL IRRIGATION AND TUBE WELL IRRIGATION.

Name of District.	Name of Village.	Depth to water table.	Cost of one acre irrigation by open well.	Area of the Estate. Chahi	Barani.	Total area in acres.	Total acre irrigation during the year.
			Rs. A. P.	Acres.	Acres.	Acres.	Acres.
Jullundur—concld.	Mukandpur ..	38 0′	2 3 9	10·37	3·33	13·70	77·89
Hoshiarpur ..	Bassi Ghulam Husain	4 4′	11 14 9	2·44	9·91	12·35	15·11
	Kala Jhangar	28.0′	4 14 3	3·18	6·48	9·66	16 01
	Dugri	8.5′	9 3 9	2·91	11·39	11·30	6 76
Gujranwala .	Chak Jagna	15 6′	2 12 9	11·03	.	11·03	66·21
	Chak Nizam	21 6′	1 15 9	20 96		20 96	132·41
	Taraunya	17 6′	1 9 6	19·85		19 85	107·57
	Chak Ramdas Old	15 0′	3 8 0	21·51	..	21·51	99·42
Sialkot	Lakhanpur .	37.6′	4 15 3	16·64	3·41	20·05	43·53
	Bharoke ..	28.6′	9 13 6	0·12	23·96	24·08	5·13
	Garhi ..	32.6′	2 15 3	1·04	22·25	23·29	29·83
	Sodhrake .	24.6′	6 15 6	9·40	8·84	18·24	39·46
	Abdali .	32.6′	5 3 9	9·68	9·27	18·95	34·76

TABLE 47—CONTINUED.

SHOWING THE ECONOMICS OF OPEN WELL IRRIGATION AND TUBE WELL IRRIGATION.

Name of District.	Name of Village.	Total expenditure under open well irrigation.							
		Land Revenue.	Outside labour.	Upkeep of bullocks.	Int. and dep. on well and Persian Wheel.	Int. and dep. on implements.	Cost of seed.	Wages of Kamins.	Miscellaneous.
		Rs. A. P.	Rs. A. P.	Rs. A. P.	Rs. A. P.	Rs. A. P.	Rs. A. P.	Rs. A. P.	Rs. A. P.
andur—contd.	Mukandpur ..	47 3 3	27 8 0	234 0 3	00 4 0	32 12 6	49 15 0	48 15 3	25 0 6
hiarpur ..	Bassi Ghulam Hussain	32 9 9	31 0 0	308 0 0	106 2 9	30 4 0	02 10 0	68 8 0	15 14 0
	Kala Jangar ..	33 8 3	82 15 0	103 10 3	47 6 3	9 13 0	54 10 0	33 8 0	1 10 0
	Dugri ..	55 0 0	40 7 3	125 10 9	41 11 0	20 11 0	25 15 0	34 0 0	2 0 3
anwala ..	Chak Jagna ..	49 11 0	212 14 0	204 2 0	64 3 0	35 4 3	36 0 3	48 3 0	4 9 0
	Chak Nizam ..	63 10 0	107 8 9	265 9 9	90 9 9	13 13 0	47 2 3	55 11 3	46 13 0
	Taraunya ..	12 8 3	147 13 6	218 0 6	20 3 0	15 11 3	80 3 0	29 8 0	70 8 0
	Chak Ramdas old ..	30 0 0	183 12 0	358 5 6	143 7 9	28 8 0	65 0 0	50 0 0	68 10 9
kot ..	Lakhanpura ..	35 14 0	33 12 0	290 7 3	65 4 3	21 8 9	42 12 6	48 3 0	4 0 0
	Bharoke ..	38 12 9	85 0 9	180 15 9	22 6 0	33 2 0	45 7 0	56 13 0	1 8 0
	Gurbi ..	10 11 3	80 0 0	231 12 0	20 9 6	25 8 3	54 3 0	55 3 0	178 3 0
	Sodhrake ..	34 8 3	52 12 0	281 4 6	77 0 6	24 0 9	26 11 6	57 3 0	41 12 6
	Abdah ..	17 6 6	50 14 0	241 2 9	57 12 6	25 14 9	42 8 0	34 15 0	50 4 9

TABLE 47—CONTINUED.

SHOWING THE ECONOMICS OF THE OPEN WELL IRRIGATION AND TUBE WELL IRRIGATION.

Name of District.	Name of Village.	Total Expenditure.	Total income in a normal year.	Net saving under open well irrigation in a normal year.	Total expenditure under Tube well irrigation.	Net saving under Tube-well irrigation in a normal year.	Profit or loss on the introduction of Tube-well irrigation.	Profit or loss per acre.
		Rs. A. P.	Rs. A. P.	Rs. A. P.	Rs. A. P.	Rs. A. P.	Rs. A. P.	Rs. A. P.
Jullundur—contd.	Mukandpur .	534 11 3	665 0 0	130 4 0	591 12 0	70 4 0	—60 0 0	—4 6 0
Hoshiarpur ..	Bassi Ghulam Husain	691 7 0	747 0 0	55 0 0	550 [illegible] 3	100 12 0	135 3 0	10 15 3
	Kala Jhangar .	367 1 3	459 0 0	90 14 9	336 11 0	121 5 0	30 6 3	3 2 3
	Dugri ..	362 7 6	460 0 0	107 8 6	310 1 3	149 14 0	42 6 3	2 15 6
Gujranwala ..	Chak Jagna ..	654 16 0	667 4 9	12 5 9	669 13 3	—1 8 6	—13 14 3	—1 4 0
	Chak Nizam ..	690 14 3	996 12 0	305 13 0	824 5 3	172 6 0	—133 7 0	—6 5 0
	Tarsunya .	594 7 6	758 0 0	163 6 6	746 3 0	11 13 0	—151 11 6	—7 10 3
	Chak Ramdas Old..	948 1 0	1,066 0 0	117 14 6	897 7 3	168 8 0	50 10 3	2 1 0
Sialkot ..	Lakhanpur ..	641 13 9	690 13 6	148 15 9	457 3 3	233 10 3	84 10 6	4 3 6
	Bharoke ..	464 1 3	689 0 0	224 14 9	428 9 3	260 6 9	35 8 0	1 7 6
	Gurhi ..	662 4 0	796 0 0	133 12 0	664 0 3	131 15 9	—1 12 3	—0 1 0
	Sodhreke .	595 6 0	651 0 0	65 11 0	478 8 9	172 7 3	116 12 3	6 6 6
	Abdali .	520 8 3	590 0 0	60 7 9	442 12 3	147 3 0	77 12 0	4 1 9

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TABLE 47—CONTINUED.

SHOWING THE ECONOMICS OF OPEN WELL IRRIGATION AND TUBE WELL IRRIGATION.

Name of District.	Name of Village.	Depth to water table.	Cost of one acre irrigation by open well.	Area of the Estate. Chahi.	Area of the Estate. Barani.	Area of the Estate. Total area in acres.	Total acre irrigation during the year.
			Rs. A. P.	Acres.	Acres.	Acres.	Acres.
Gujrat ..	Gurali ..	10·6′	4 0 9	11·85	2·71	14·56	64·80
	Pindi Hasna ..	17·6′	4 13 0	8 28	2·95	11·23	26·45
	Fatehpur ..	9·6′	3 14 9	9·40	3·71	13·11	35·14
	Chechian ..	11·6′	7 0 0	13·10	4·95	18·05	43·35
Amritsar ..	Lola ..	20·0′	2 14 0	12·11	7·04	19·15	71·14
	Ramdev Wali ..	20·0′	2 11 8	9·42	8·68	18·08	60·92
	Hamidpur ..	16·6′	5 8 3	8·64	13·73	22·37	40·06
	Rampur ..	16·0′	3 2 3	11·41	15·39	28·80	80·74
	Sadhpur ..	18·6′	4 8 6	11·64	6·07	17·71	40·92
Multan ..	Faridpur ..	32·6′	3 6 0	18·34	..	18·34	121·77
	Khanpur ..	37·6′	3 11 9	22·51	..	22·51	67·94
	Inaitpur ..	37·6′	2 13 0	18·94	Nahri 3·00	21·94	106·40
	Jarala ..	17·6′	1 15 3	17·40	..	17·40	88·68

TABLE 47—CONTINUED.

SHOWING THE ECONOMICS OF OPEN WELL IRRIGATION AND TUBE WELL IRRIGATION.

Name of District.	Name of Village.	Total expenditure under open well irrigation.							
		Land Revenue	Outside labour.	Upkeep of bullocks.	Int. and dep. on well and Persian Wheel.	Int. and dep. on implements.	Cost of seed.	Wages of Kamins.	Miscellaneous.
		Rs. A. P.	Rs. A. P.	Rs. A. P.	Rs. A. P.	Rs. A. P.	Rs. A. P.	Rs. A. P.	Rs. A. P.
Gujrat—*contd.*	Gurah .	38 4 0	92 4 0	273 2 0	150 10 0	9 13 6	50 8 0	35 0 0	41 15 0
	Pindi Hasna ..	18 2 0	24 10 0	209 3 3	64 13 3	27 0 0	55 12 0	34 7 0	1 12 0
	Fatehpur .	28 3 0	27 0 0	141 5 0	83 7 6	20 13 0	31 3 3	33 2 6	1 8 0
	Chechian .	22 7 9	8 8 0	300 2 0	154 14 3	44 1 0	38 5 0	43 13 0	1 12 0
Amritsar ..	Lola ..	00 14 0	134 10 0	283 1 0	43 11 0	33 0 0	43 13 0	32 10 0	8 2 0
	Ramdev Wali ..	36 2 3	23 8 0	240 2 0	27 0 0	32 14 3	31 14 0	54 10 3	11 8 0
	Hamidpur ..	38 7 9	153 12 0	202 6 0	08 8 0	24 7 6	58 4 0	38 2 0	1 1 0
	Rampur ..	76 13 0	95 4 0	297 3 9	78 8 0	32 15 0	48 4 3	33 0 0	1 12 0
	Sadhpur ..	40 15 0	42 0 0	221 7 0	75 0 0	27 12 3	30 3 0	30 0 0	0 0 0
Multan ..	Faridpur ..	27 4 0	12 8 0	345 13 0	127 8 0	12 8 6	58 4 3	40 0 0	1 0 0
	Khanpur ..	..	..	274 6 0	22 8 0	16 14 9	35 4 0	30 0 0	0 14 0
	Inaitpur ..	53 0 0	8 12 0	359 10 3	13 0 0	10 8 0	44 15 9	30 12 6	0 8 0
	Jarala ..	35 7 3	65 10 6	80 12 3	90 14 0	10 3 6	20 14 3	19 8 0	0 12 0

TABLE 47—CONTINUED.

SHOWING THE ECONOMICS OF OPEN WELL IRRIGATION AND TUBE WELL IRRIGATION.

Name of District.	Name of Village.	Total Expenditure.	Total income in a normal year.	Net saving under open well irrigation in a normal year.	Total expenditure under Tube-well irrigation.	Net saving under Tube well irrigation in a normal year.	Profit or loss on the introduction of tube well irrigation.	Profit or loss per acre.
		Rs. A. P.	Rs. A. P.	Rs. A. P.	Rs. A. P.	Rs. A. P.	Rs. A. P.	Rs. A. P.
Gujrat—concld.	Gurali ..	791 0 3	962 0 0	200 15 9	507 1 0	304 14 3	103 14 6	7 2 3
	Pindi Hasna ..	433 12 3	596 0 0	160 3 9	386 0 3	209 15 9	49 12 0	4 6 9
	Fatehpur ..	308 11 0	914 0 0	216 5 0	339 1 0	277 15 9	32 10 0	2 7 9
	Chechian ..	613 15 6	624 0 0	10 0 6	440 6 9	163 9 3	173 8 9	0 0 0
Amritsar ..	Lola ..	651 8 6	752 0 0	100 7 6	660 5 9	91 10 3	—8 13 3	—0 7 3
	Ramdev Wali ..	466 12 0	695 0 0	228 4 0	483 11 3	211 4 9	—19 15 3	—0 15 0
	Hamidpur ..	703 2 3	726 0 0	22 13 9	602 3 3	123 12 9	100 15 0	4 8 3
	Rampur ..	664 5 0	777 0 0	112 11 0	652 4 3	124 11 9	12 0 9	0 7 3
	Sadhpur ..	489 5 0	977 0 0	190 11 0	429 0 0	248 0 0	57 5 0	3 3 9
Multan ..	Faridpur ..	604 14 3	653 0 0	48 1 9	558 0 3	94 15 9	46 14 0	2 8 9
	Khanpur ..	386 7 9	403 0 0	16 8 3	336 10 6	66 5 9	49 13 3	2 3 9
	Inaitpur ..	530 2 9	706 0 0	175 13 6	549 7 9	156 8 3	—19 5 3	—0 14 6
	Jarala ..	333 1 9	495 0 0	161 14 3	426 5 6	68 10 6	—93 3 0	—5 5 3

TABLE 47—*continued*.

SHOWING THE ECONOMICS OF OPEN WELL IRRIGATION AND TUBE WELL IRRIGATION.

Name of District.	Name of Village.	Depth to water-table	Cost of one acre irrigation by open well.	Area of the Estate.			Total acre irrigation during the year.
				Chahi.	Barani	Total area in acres.	
			Rs. A. P.	Acres.	Acres.	Acres.	Acres.
Multan—*concld.*	Sarai Sidhu ..	19·0′	5 3 0	14·15	.	14·15	63·58
	Dorana Langana	16·6′	0 14 0	16·50	Nahri 2·09	18·59	93·28
	Nilkot	8·9′	3 10 9	1·60	Chahi Nahri 13·43 Nahri 6·25	21·18	71·92
Ludhiana ..	Samrala ..	32·2′	4 15 3	7·37	7·81	15·18	69·69
	Khanna .	37·6′	2 15 9	17·35	12·84	30·19	116·63
Gurgaon ..	Tauru ..	28·0′	3 10 0	8·84	23·13	31·07	60·63
	Bissar Akbarpur ..	48·6′	6 0 9	7·40	13·00	20·40	41·37
	Baboopur ..	18·0′	6 0 0	3·00	39·84	42·84	15·00
	Chanse .	30·0′	4 3 0	0·81	42·39	43·20	5·30
	Pathrali ..	30·0′	0 7 3	6·09	41·81	47·90	24·51
	Nagina ..	13·6′	5 0 3	4·00	30·85	34·34	17·50
	Ter ..	22·0′	4 3 6	4·50	35·34	[illegible]	[illegible]

TABLE 47.—CONTINUED.

SHOWING THE ECONOMICS OF OPEN WELL IRRIGATION AND TUBE WELL IRRIGATION.

Name of District.	Name of Village.	Total expenditure under open well irrigation.							
		Land Revenue.	Outside labour.	Upkeep of bullocks.	Int. and dep. on well and Persian Wheel.	Int. and dep. on implements.	Cost of seed.	Wages of Kamins.	Miscellaneous.
		Rs. A. P.	Rs. A. P.	Rs. A. P.	Rs. A. P.	Rs. A. P.	Rs. A. P.	Rs. A. P.	Rs. A. P.
Multan—*contd.*	Sarai Sidhu ..	20 0 0	16 0 6	367 8 3	51 5 9	14 14 3	29 8 0	21 8 0	1 10 6
	Dorana Langana ..	6 4 0	..	131 4 6	6 12 0	19 15 9	41 8 0	32 15 0	1 8 0
	Nilkot ..	71 9 3	34 8 0	208 5 0	132 2 9	16 9 6	63 13 0	37 10 0	45 3 0
Ludhiana ..	Samrala ..	41 4 3	119 4 6	345 0 6	117 8 6	28 0 3	35 4 5	47 6 0	19 1 0
	Khanna ..	115 8 9	250 13 9	391 3 9	95 10 6	35 6 0	61 2 0	41 3 3	1 2 0
Gurgaon ..	Tauru ..	53 9 9	10 0 6	255 12 6	74 2 6	19 7 6	50 12 0	23 13 9	7 0 0
	Bissar Akbarpur ..	26 14 0	34 9 0	167 13 6	136 11 0	29 10 3	30 15 3	23 8 3	1 11 0
	Baboopur ..	100 4 6	155 0 3	162 7 0	70 2 0	18 2 6	30 11 9	22 1 3	2 0 0
	Chanse ..	64 4 3	55 10 9	232 15 6	11 14 9	24 6 0	44 10 0	32 14 0	8 2 0
	Pathrali ..	66 12 6	305 10 0	300 1 3	122 4 6	31 11 0	68 6 6	50 12 3	3 8 0
	Nagina ..	77 9 9	146 5 0	192 12 6	44 12 0	27 11 3	51 12 0	17 13 3	1 10 0
	Ter ..	77 10 0	116 8 0	179 9 9	23 4 3	23 0 0	34 14 0	32 13 9	163 9 6

TABLE 47.—CONCLUDED.

SHOWING THE ECONOMICS OF OPEN WELL IRRIGATION AND TUBE WELL IRRIGATION.

Name of District.	Name of Village	Total Expenditure.	Total income in a normal year.	Net saving under open well irrigation in a normal year.	Total expenditure under Tube well irrigation.	Net saving under Tube-well irrigation in a normal year.	Profit or loss on the introduction of tube well irrigation.	Profit or loss per acre.
		Rs. A. P.	Rs. A. P.	Rs. A. P.	Rs. A. P.	Rs. A. P.	Rs. A. P.	Rs. A. P.
Multan—concld.	Sarai Sidhu	522 0 9	733 0 0	210 9 3	372 8 9	360 7 3	149 14 0	10 9 0
	Darana Langana	239 0 3	342 0 0	102 6 9	448 9 3	—106 9 3	—209 0 0	—11 3 0
Ludhiana	Nilkot	609 12 0	732 0 0	122 3 0	561 11 0	170 5 0	48 1 6	2 4 3
	Samrala	752 12 9	850 0 0	100 3 3	616 11 6	212 4 6	136 1 3	6 15 6
	Khanna	998 2 6	1,017 0 0	18 14 0	999 7 6	17 8 0	—1 5 6	—0 0 9
Gurgaon	Tauru	494 9 6	932 0 0	437 6 6	456 14 0	475 2 0	37 11 0	1 2 3
	Bissar Akbarpur	451 12 3	722 0 0	270 3 9	325 9 6	390 0 6	120 2 9	6 3 0
	Baboopur	560 13 3	969 0 0	408 2 9	500 14 0	462 2 0	53 15 3	1 4 0
	Chanw	474 13 3	788 0 0	313 2 9	404 7 0	323 8 3	10 5 6	0 3 9
	Pathrali	949 2 3	1,415 0 0	465 13 9	788 9 3	626 6 0	160 0 0	3 5 9
	Nagina	560 5 9	731 0 0	170 10 3	510 8 6	220 7 6	49 13 3	1 6 9
	Ter	651 5 3	735 0 0	83 10 9	632 15 9	102 0 3	18 5 6	0 7 3

TABLE 48.

SHOWING RAINFALL AND RUN-OFF FOR THE MONSOON SEASON, 1938.

Date.	Rainfall in inches.	Intensity of rainfall per hour.	Percentage rainfall received as Run-off.	Average Run-off cusecs per square mile.	Maximum Run-off cusecs per square mile.	Remarks.
1. Khambranwala Site.						
16th July, 1938 ..	0·39	0·72	0·41	1·46	2·47	
22nd July, 1938 ..	0·76	0·10	.0·05	0·12	0·41	
23rd July, 1938 ..	3.60	0·40	1·53	3·89	11·01	
24th July, 1933 ..	0 49	0·08	0·35	0·39	1·38	
2nd August, 1938 ..	0.48	0·48	0·25	0·46	0·83	
12th August, 1938 ..	0·25	0·33	0·23	0·46	1·00	
16th August, 1938 ..	1·70	0·33	0·16	0·34	1·28	
17th August, 1938 ..	0·43	0·21	0·15	0·26	0·46	
21st August, 1938 ..	1 62	0·65	0·55	1·00	3·33	
28th August, 1938 ..	0·32	1·28	0·06	0·30	0·33	
2. Sialkot Site.						
15th July, 1938 ..	1·00	2·00	4·87	6·83	12·33	
22nd July, 1938 ..	1·76	0·70	6·04	7·25	19·79	
23rd July, 1938 ..	3·94	0·82	13·80*	11·92	44·39	*The observations were still in progress when the flood water from Aik Nallah entered the area.
2nd August, 1938 ..	0·85	2·55	12·70	8·25	18·33	
12th August, 1938 ..	1·28	1·92	9·54	16·60	44·81	
16th August, 1938 ..	1·72	0·63	5·95	15·58	32·66	
21st August, 1938 ..	1·82	0·91	9·07	29·50	48·97	
26th August, 1938 ..	1·10	0·60	6·75	12·69	24·74	
3. Sagar Site.						
27th June, 1938 .	0·44	0·59	5·87	1·16	4·08	
24th July, 1938 ..	1·20	0·00	7·47	8·28	17·12	
26th July, 1938 ..	0·25	0·50	0·56	3·12	6·84	
2nd August, 1938 ..	0·38	0·25	5·92	6·80	12·52	
15th August, 1938 ..	0·63	0·59	10·70	9·36	20·36	
16th August, 1938 ..	1·32	0·88	19·00	22·00	38·00	
21st August, 1938 ..	1·38	0.28	16·90	16·44	29·83	
2nd September, 1938	0·55	0·37	7·98	5·28	21·16	

FIG. 72

A PART PLAN OF RECHNA DOAB SHOWING THE LINES OF VILLAGES UNDER SPECIAL THUR GIRDAWRI

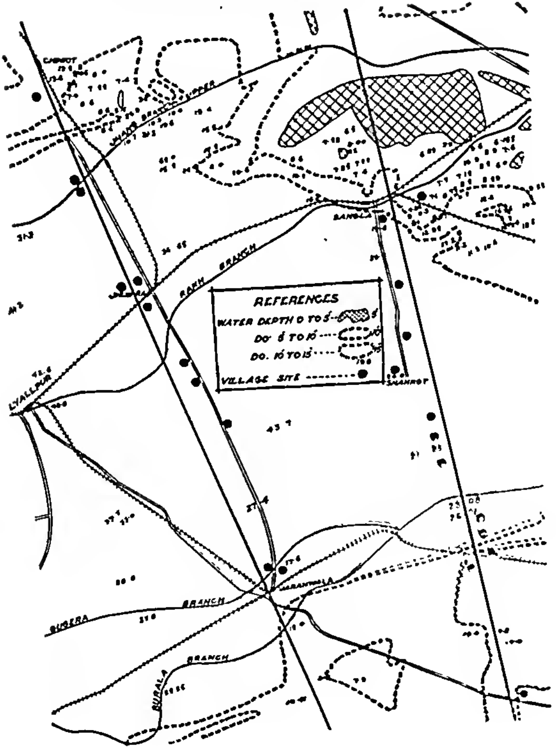


FIG. 73

SHOWING THE DISTRIBUTION OF SALT IN SOIL PROFILES

CHAK No 266 R.B.

L. C. C.

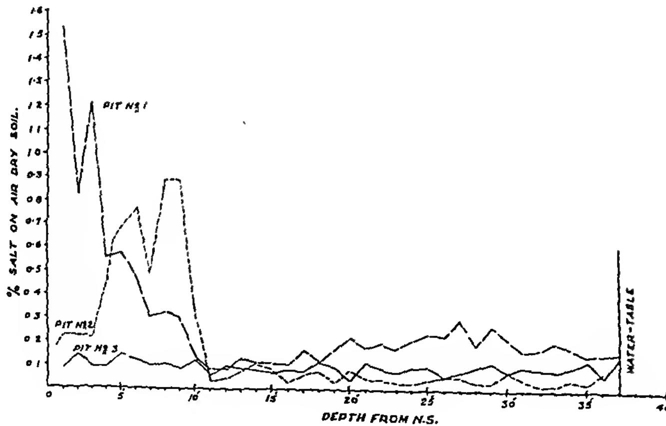
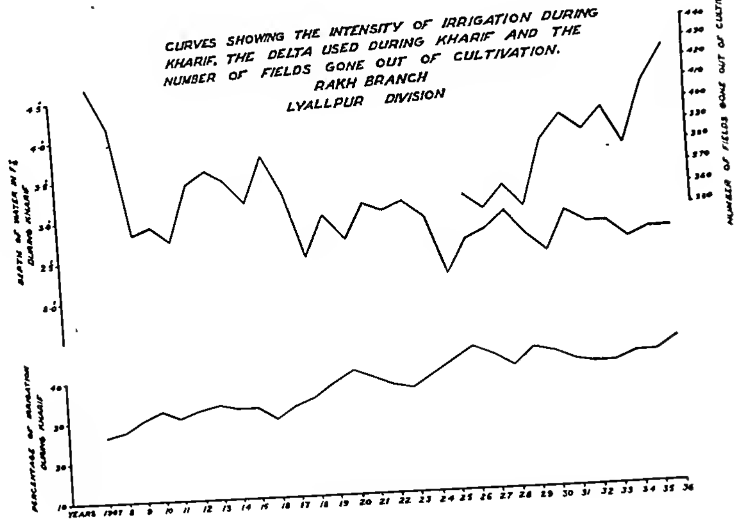


FIG. 74


CURVES SHOWING THE INTENSITY OF IRRIGATION DURING KHARIF. THE DELTA USED DURING KHARIF AND THE NUMBER OF FIELDS GONE OUT OF CULTIVATION.
RAKH BRANCH
LYALLPUR DIVISION
DEPTH OF WATER IN FT DURING KHARIF
PERCENTAGE OF IRRIGATION DURING KHARIF
NUMBER OF FIELDS GONE OUT OF CULTIVATION
YEARS

SHOWING THE ZONE OF ACCUMULATION OF SALT IN A SOIL PROFILE UNDER A COTTON FIELD CHAK Nº 266 RB

FIG 15

FIG. 76

SHOWING THE ZONE OF ACCUMULATION OF SALT IN A SOIL PROFILE UNDER A COTTON FIELD CHAK NO 61 G B

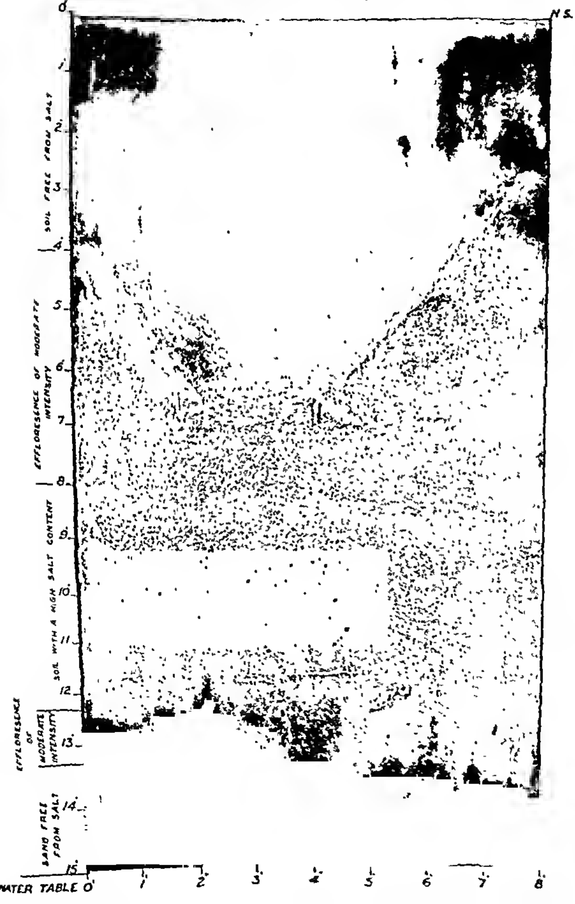


FIG. 78

SHOWING THE DISTRIBUTION OF SALT IN THE SOIL PROFILE
UNDER DIFFERENT SYSTEMS OF CROPPING
AT THE END OF RABI 1938 — 39

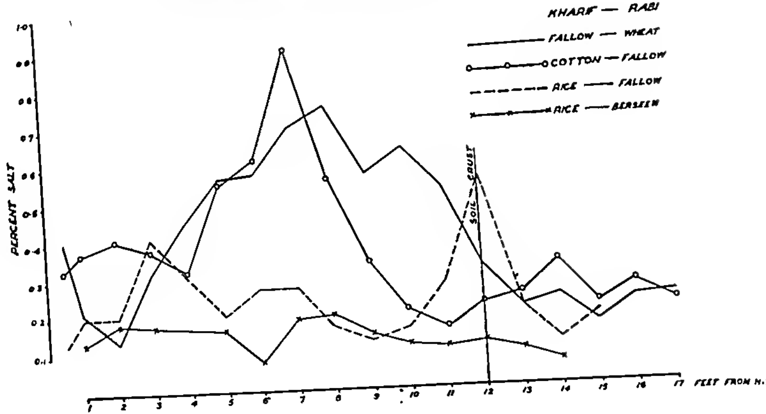


FIG. 79.

PART PLAN OF RENALA ESTATE
SHOWING AREAS UNDER RECLAMATION

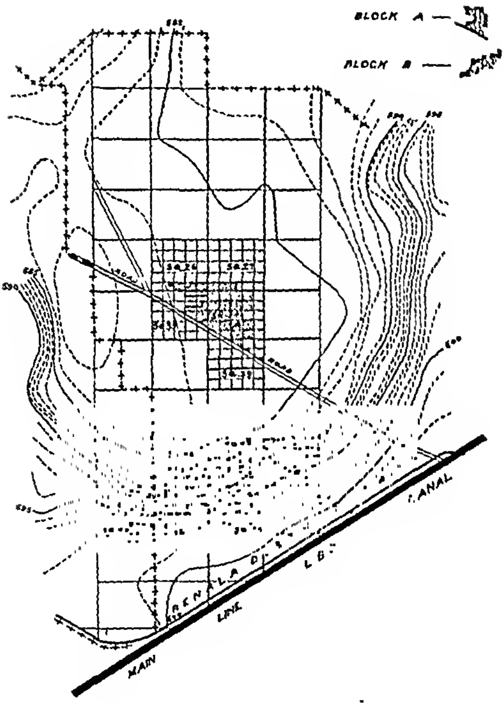


FIG. 80

SHOWING DEPTHS OF SUB-SOIL WATER LEVELS IN PLOTS UNDER RECLAMATION AT RENALA

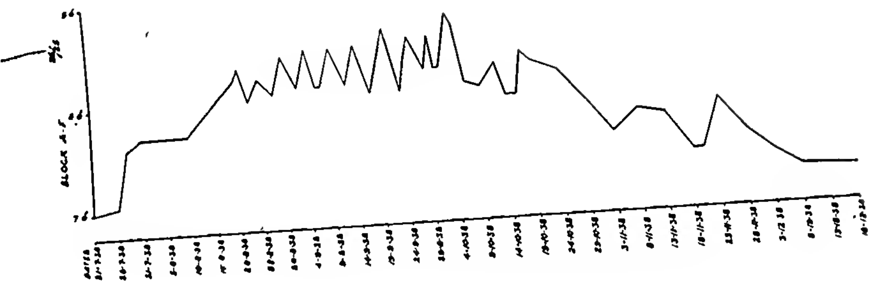


FIG. 81

SHOWING THE SALT CONTENT OF SUBSOIL WATER IN FIELDS UNDER RECLAMATION AT RENALA

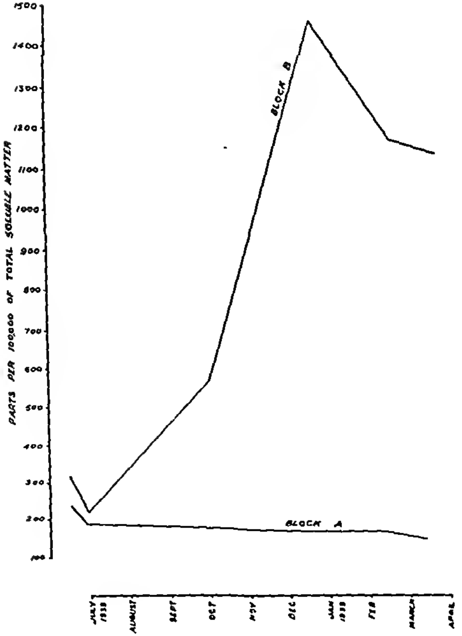


FIG. 82

L. J. C.
188 N.-B.
COTTON 1938.

FIG. 83

INDEX PLAN
SHOWING THE SALT CONTENT OF WELL WATERS
ALONG THE LOWER RANIWAH DRAIN

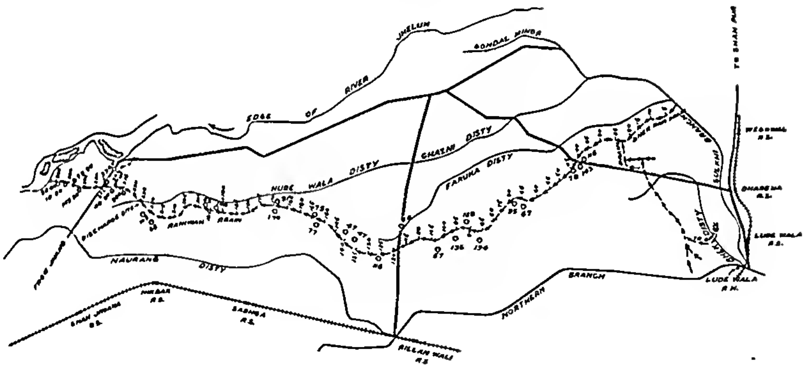


FIG. 84

LOWER RANIWAH DRAIN
CROSS SECTION AT R.D. 230,000
SHOWING THE SALT CONTENT AND THE PH VALUE OF SOILS
AND WATERS FROM THE PROFILES EXPOSED ON EITHER SIDE.

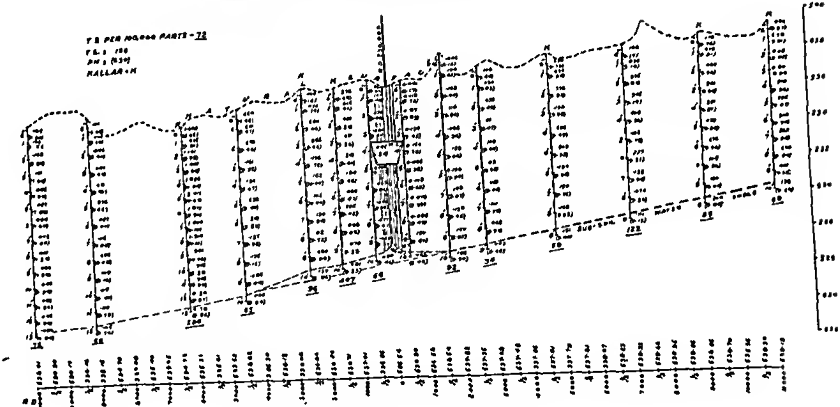


FIG. 85

CHAKANWALI RECLAMATION FARM.

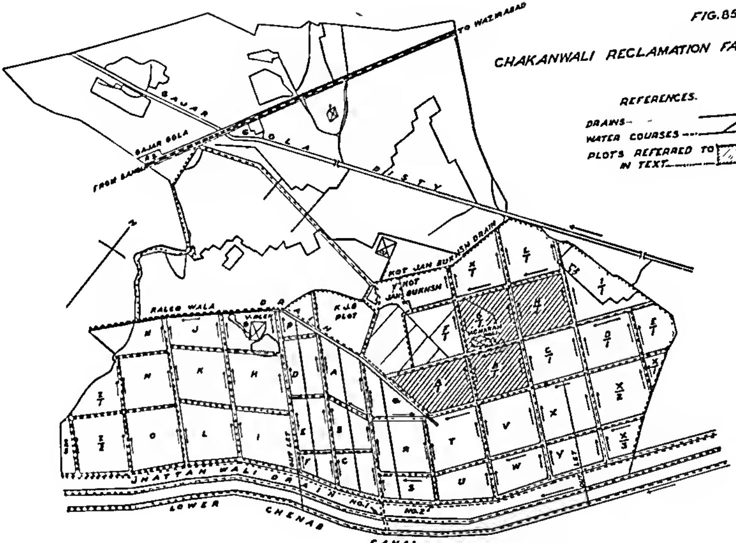


FIG. 86

MAP SHOWING THE MAIN THE BRANCH & THE SUBSIDIARY DRAINS OF THE CHAJ DOAB

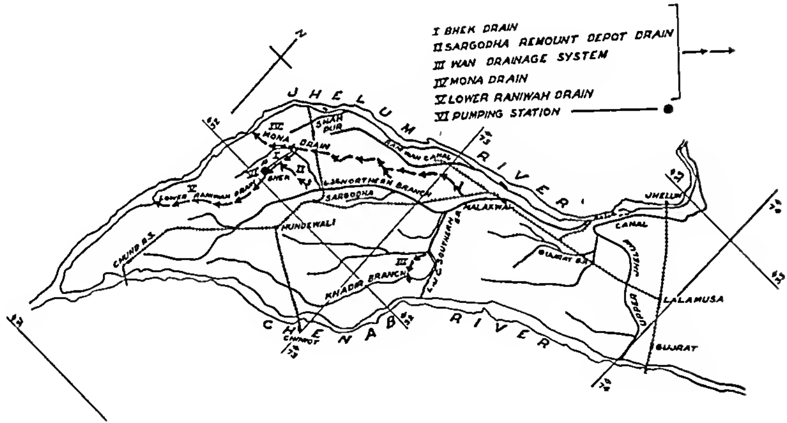


FIG.87

SHOWING THE SALT CONTENT OF WATERS OF THE BHEK DRAIN AT THE BHEK PUMPING STATION

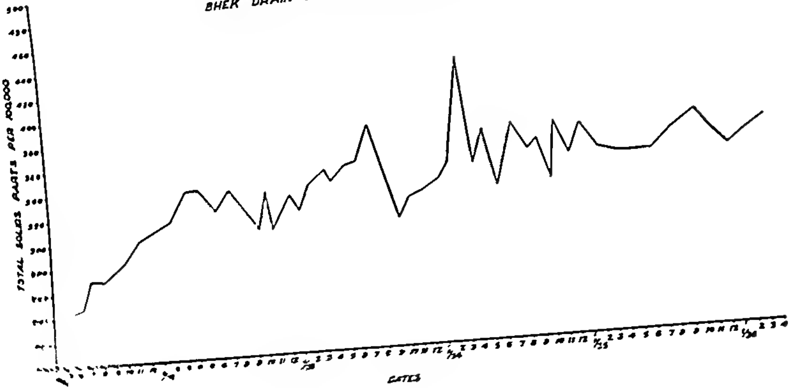


FIG.88

MAP SHOWING THE MAIN DRAINS & THE PUMPING STATIONS OF THE RECHNA DOAB

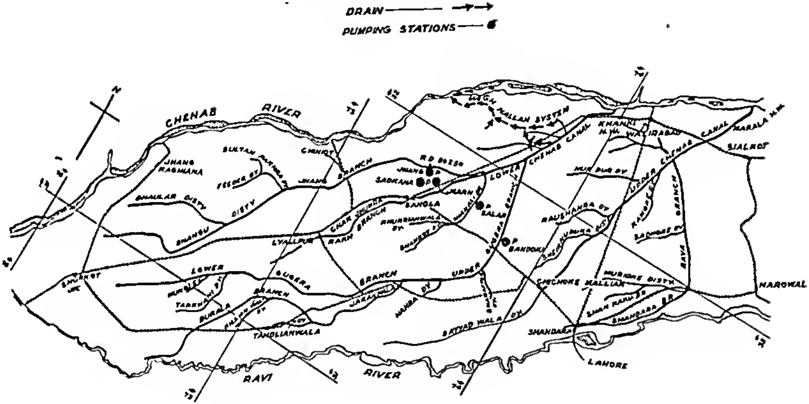


FIG. 89

SHOWING RAINFALL & WATER TABLE MEASUREMENTS IN THE PALLKHU NALLAH AREA NEAR KHAMBRANWALA

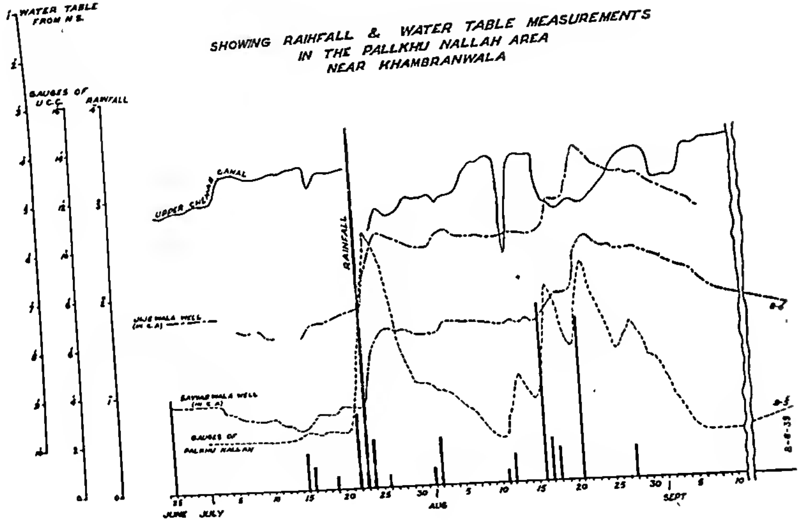
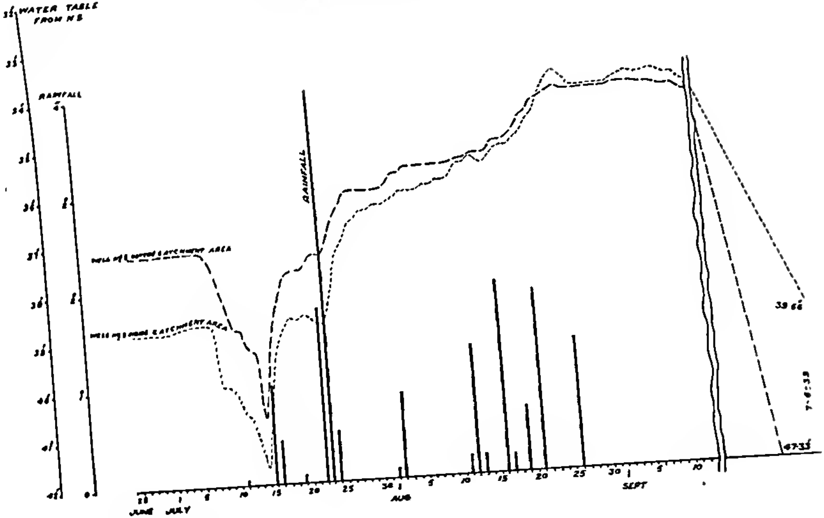


FIG. 90

SHOWING WELL OBSERVATIONS & RAINFALL
SIALKOT PASRUR AREA.



value of the soil was made. Table 49 gives the results of some of the soils examined and Figs. 91—102 give the results in graphical form.

The results show that a significant correlation co-efficient is obtained between the yield of wheat and the manganese and available phosphate contents of the soil. In general, soils giving a high yield of wheat have a low manganese and high available phosphate content. From the known effects of phosphate manuring a high correlation between yield and available phosphate would be expected since the water available for the wheat crop in the Punjab is the main factor limiting the yield. The effect of manganese cannot as yet be explained. The soils of the Punjab are generally alkaline, but the range of pH values of wheat soils is pH 7 to pH 8·5. No correlation was found between the yield of wheat and the pH value. Within this range of pH values, manganese is insoluble; it seems, therefore, that manganese may not affect directly the yield of wheat, but some other factors determining the accumulation of manganese in the soil may be the real cause of the relationship. The investigation is to be continued both in the laboratory and in the field.

Electrodialysis of Soil : Fixation of Manganese.—To further elucidate the effect of the presence of various bases commonly present in the exchange complex of the soils of the Punjab on the accumulation of manganese, manganese soils were artifically prepared from three acid treated soils differing widely in their mechanical composition and exchange capacity. Four sets of soils with pH varying from 4 to 10 were prepared by adding hydroxides of sodium, potassium, calcium and magnesium separately. These soils were subjected to electrodialysis at 100 milliamperes for 5 hours. Manganese and the bases coming in the electrodialysates were determined. As a result of this study it was revealed that the recovery of manganese was least in the set of soils to which calcium was added. The presence of potassium also showed a similar effect although to a less extent than calcium. In the presence of sodium or magnesium the recovery of manganese was much more than with calcium and potassium. On the basis of this investigation the effects of the bases on the fixation of manganese are brought out. In the Punjab, deterioration of the soil is accompanied by an increase of sodium over calcium in the exchange complex and hence with an increased sodium content in the soil more and more manganese becomes available to plant life and this may be one of the reasons of the decrease in the yield on deteriorated soils.

Volumetric estimation of the Sulphate Contents of Soils and Waters.—A volumetric method of estimating the sulphate content of soils and waters by titrating with standard barium nitrate solution, based on the use of rhodizonic acid as an external indicator has been developed. The sulphate contents of a large number of water extracts of soils and waters were determined both volumetrically and gravi-

metrically. Some of the results are given in Table 50. These show a fairly good agreement. The technique of the volumetric method has been standardised.

In order to avoid the time consuming process of preparing water extracts, the soils were shaken with salt solutions of amonium carbonate, potassium nitrate, sodium chloride, potassium-chloride and ammonium chloride of varying strength and their sulphate contents determined. It has been shown that if normal solutions are used than the sulphate results obtained in the presence of KNO_3 and $NaNO_3$ were very much less than if they were determined gravimetrically. With decinormal solutions, the KNO_3 and $NaNO_3$ affect the results up to 2-3 per cent. of the sulphate content. With 0·05 N solutions the results are the same as those obtained with 0·1 concentrations. Sulphate estimations were not affected by the presence of N/10 $(NH_4)_2CO_3$ solutions. Therefore if the extraction of the soils is carried with N/10 $(NH_4)_2CO_3$ it is possible to estimate both chlorides and sulphates in the extracts.

Further, it has been found possible to use rhodizonic acid as an internal indicator if the titration is done in the presence of alcohol. The colour of the indicator changes from yellow to rose red at the end-point. The precipitate of barium sulphate forms at once and the frequent warming of the solution during titration is obviated. The soil extracts may be prepared by "salting" the suspensions with a little potassium nitrate or sodium nitrate and the sulphate estimated in a 25 cc. portion of the extract in the presence of an equal volume of alcohol using about 0·01 gm. of rhodizonic acid. The method is similar to that used with tetrahydroxyquinone (THQ) indicator but with the latter about 0·2 gm. of the indicator is needed for each titration. With the use of the above technique the work in connection with the soluble salt determination for soil survey work and water analysis is greatly simplified.

Migration Velocity of Soils.—If an electric current of the order of a few microamperes is passed through soil suspensions a movement of the soil column takes place towards the positive pole. The rate of this migration—migration velocity—is determined by the potential, current density and the time for which the current is passed. If the migration velocities of soils are examined at definite current densities and fixed intervals the following interesting relationships of the migration velocity are obtained with pH and the bases present in the exchange complex :—

(i) Maximum migration velocity is obtained near pH 7. With further increase in the pH the migration decreased till at about 10·8 it was almost negligible. With further increase in pH a reversal of migration, *i.e.*, a decrease instead of increase was observed.

(ii) The monovalent bases when present in the exchange complex resulted in soils manifesting greater migration velocity than the divalent bases.

(iii) Soils containing humus gave a comparatively greater migration at various pH values than the same soils after the humus had been removed.

An examination of a number of soils revealed that, when a comparison of the downward fall of the particles in soil suspensions with and without current was made, particles below ·008 mm. were affected by the passage of the current.

TABLE 49.

ANALYSES OF SOILS OF THE PUNJAB IN RELATION TO THE YIELD OF WHEAT.

TABLE 49.

ANALYSES OF SOILS OF THE PUNJAB IN RELATION TO THE YIELD OF WHEAT.

Serial No.	Registered No.	District.	Depth of Soil Sample.	Yield in maunds per acre.	Expressed in milli-equivalents. Mn.	Ca	K.	P. in P. P. M.	Percentage T. S.	pH.	Remarks.
									Per cent.		
1	1771	Jhang ..	0—9" (1)	20	1·30	8·10	0·62	20·03	0·055	7·70	
2	72		9"—18" (2)	20	1·30	7·0	0·50	20·10	0·060	7·80	
3	73		1	7·5	1·45	14·1	0·55	13·08	0·050	7·03	
4	74		2	7·5	1·85	8·7	0·42	12·21	0·050	8·0	
5	211		1	2·5	2·75	4·0	1·0	6·08	0·110	7·35	
6	12		2	2·5	1·45	2·2	0·55	5·23	0·08	7·66	
7	1767		1	15·0	1·50	13·8	0·60	20·06	0·05	7·82	
8	1768		2	15·0	3·00	13·0	0·90	13·05	0·06	7·83	
9	25	Lyallpur ..	1	12·5	2·20	10·20	0·40	31·40	0·07	7·46	
10	26		2	12·5	2·60	13·6	0·43	17·44	0·06	7·33	
11	27		1	20·0	0·1	11·6	0·32	41·42	0·07	7·36	

12	29		2	20·0	0·1	13·0	0·23	22·24	0·10	7·29
13	22		1	7·5	2·25	14·20	0·50	16·13	0·30	6·95
14	30		2	7·5	1·40	16·60	0·35	9·59	0·23	7·22
15	5		1	5·0	2·60	7·80	0·48	8·72	0·18	7·37
16	6		2	5·0	2·45	9·00	0·73	8·72	0·37	7·66
17	423	Gujrat ..	1	20	1·15	11·6	0·24	48·83	0·07	7·36
18	24		2	20	1·55	12·0	0·58	17·89	0·08	8·12
19	2511		1	15	0·50	13·6	1·35	31·01	0·08	7·39
20	12		2	15	2·20	14·40	1·85	17·44	0·09	7·22
21	23		1	7·5	1·90	16·2	1·60	14·82	0·07	7·17
22	24		2	7·5	1·63	13·40	1·65	10·16	0·07	7·12
23	45		1	4·0	2·40	10·40	0·14	13·08	0·07	7·20
24	46		2	4·0	2·75	12·2	0·25	9·30	0·07	7·28
25	269	Shahpur	1	3·0	2·40	7·8	0·67	13·08	0·05	7·69
26	270		2	3·0	3·10	10·0	0·50	11·34	0·05	7·72
27	471		1	15·0	1·0	14·4	0·97	41·04	0·05	8·22
28	472		2	15·0	2·5	14·10	1·25	43·60	0·05	8·15
29	477		1	20·0	2·0	18·3	0·98	73·25	0·05	8·0
30	634		2	20·0	1·7	11·1	0·56	27·02	0·06	8·42
31	653		1	8·0	1·55	18·6	0·58	22·68	0·036	8·55

TABLE 49—CONCLUDED.

ANALYSIS OF SOILS OF THE PUNJAB IN RELATION TO THE YIELD OF WHEAT—CONCLUDED.

Serial No.	Registered No.	District.	Depth of Soil Sample.	Yield in maunds per acre.	Expressed in milli-equivalents. M.	Expressed in milli-equivalents. Ca.	Expressed in milli-equivalents. K.	P. in P. P. M.	Per-centage T. S.	pH.	Remarks.
									Per cent.		
32	651		2	8·0	2·70	19·0	0·59	22·63	0·067	8·50	
33	1951	Gujranwala ..	0"—9" (1)	20·0	0·50	9·30	0·67	62·78	0·035	7·62	
34	1962		9"—18" (2)	20·0	0·60	14·10	0·71	27·00	0·050	7·87	
35	1963		1	5·0	1·75	12·40	0·20	14·82	0·070	7·82	
36	1362		2	5·0	3·00	15·30	0·10	7·85	0·010	7·92	
37	2247		1	7·5	3·30	5·20	1·23	38·37	0·30	8·88	
38	2248		2	7·5	2·80	4·60	1·65	43·60	0·20	8·68	
39	1953		1	12·5	1·10	7·80	1·20	34·88	0·077	7·42	
40	1954		2	12·5	1·40	9·60	0·80	10·47	0·083	7·64	
41	1111	Sheikhupura ..	1	5·0	1·30	7·0	1·54	17·44	0·25	7·47	
42	1112		2	3·0	3·0	20·4	0·83	12·21	0·50	7·58	

43	1115		1	7·5	2·8	13·4	1·05	36·52	0·10	8·85
44	1116		2	7·5	2·0	12·0	0·86	27·92	0·21	8·77
45	1117		1	20·0	0·7	10·0	0·96	30·22	0·695	8·88
46	1118		2	20·0	1·75	9·60	1·21	30·24	0·160	8·87
47	2012	Multan ..	1	20·2	2·45	0·20	1·14	27·6	0·67	7·74
48	2013		2	20·2	1·40	10·40	0·84	31·38	0·007	7·58
49	44		1	15·0	1·75	9·60	0·85	26·10	0·656	7·58
50	45		2	15·0	0·65	8·60	1·00	8·72	0·068	7·50
51	46		1	7·5	1·70	12·80	0·50	8·72	0·068	7·49
52	47		2	7·5	2·05	9·80	0·57	6·11	0·003	7·60
53	48		1	3·0	3·40	5·00	0·29	5·23	0·070	7·54
54	49		2	3·0	2·45	0·00	0·70	4·36	0·070	7·62
55	2611	Montgomery ..	1	8·0	1·65	7·3	0·8	17·44	0·05	8·88
56	12		2	8·0	2·40	10·9	0·8	4·36	0·68	7·94
57	13		1	20·0	1·80	9·30	1·05	41·88	0·665	7·02
58	14		2	20·0	1·15	9·30	1·35	7·85	0·625	7·84
59	17		1	4·0	2·9	6·50	0·90	27·00	0·136	8·10
60	18		2	4·0	2·45	10·3	0·90	6·96	0·063	8·0
61	21		1	3·0	2·0	13·1	1·85	12·21	0·097	7·75
62	22		2	3·6	2·5	9·1	1·84	7·41	0·688	7·71

TABLE 50.

COMPARISON OF THE VOLUMETRIC ESTIMATION OF THE SULPHATE CONTENT OF SOIL EXTRACTS.

Serial No.	Registered No.	SO_4 expressed as percentage Na_2SO_4.	
		Volumetric.	Gravimetric.
1	3214	0·0107	0·0158
2	3212	0·0142	0·0189
3	3219	0·0214	0·0201
4	2889	0·0355	0·0385
5	2372	0·0355	0·0460
6	2371	0·0390	0·0350
7	2387	0·0523	0·0499
8	3203	0·0568	0·0640
9	2373	0·0570	0·0560
10	2389	0·0852	0·0972
11	2335	0·0923	0·0969
12	2365	0·1314	0·1390
13	2377	0·1775	0·1662
14	3209	0·1827	0·1560
15	2368	0·1017	0·2383
16	2304	0·1053	0·2249
17	2362	0·2648	0·2374
18	2347	0·2340	0·2627
19	2·330	0·3124	0·3091
20	2418	0·3632	0·4447
21	2420	0·3976	0·3183
22	2283	0·4092	0·4217
23	2410	0·4686	0·3337
24	2288	0·6461	0·6321
25	2341	1·0235	1·0410
26	2·333	1·0205	0·9654
27	2302	1·2177	1·3086
28	2284	1·3670	1·3470
29	2252	2·0118	2·6320
30	2286	2·010	2·2862
31	2318	3·6146	3·5119

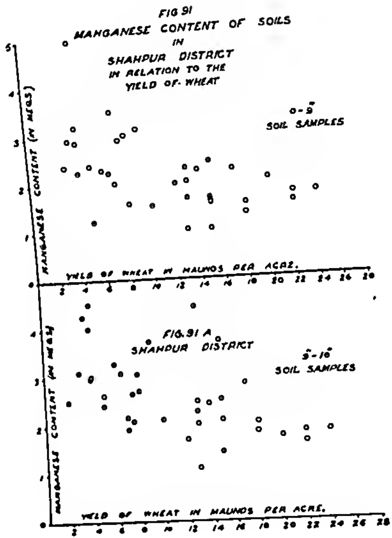


FIG 91
MANGANESE CONTENT OF SOILS IN SHAHPUR DISTRICT IN RELATION TO THE YIELD OF WHEAT
0-9" SOIL SAMPLES
MANGANESE CONTENT (IN MEQS)
YIELD OF WHEAT IN MAUNDS PER ACRE.
FIG.91 A
SHAHPUR DISTRICT
9"-18" SOIL SAMPLES
MANGANESE CONTENT (IN MEQS)
YIELD OF WHEAT IN MAUNDS PER ACRE.

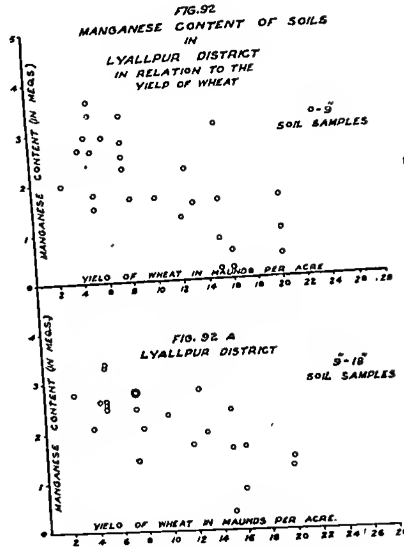


FIG.92
MANGANESE CONTENT OF SOILS IN LYALLPUR DISTRICT IN RELATION TO THE YIELD OF WHEAT
0-9" SOIL SAMPLES
MANGANESE CONTENT (IN MEQS)
YIELD OF WHEAT IN MAUNDS PER ACRE
FIG. 92 A
LYALLPUR DISTRICT
9"-18" SOIL SAMPLES
MANGANESE CONTENT (IN MEQS)
YIELD OF WHEAT IN MAUNDS PER ACRE.

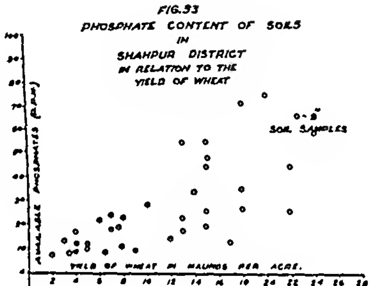


FIG.33
PHOSPHATE CONTENT OF SOILS
IN
SHAHPUR DISTRICT
IN RELATION TO THE
YIELD OF WHEAT
0-9"
SOIL SAMPLES
AVAILABLE PHOSPHATES (P.P.M.)
YIELD OF WHEAT IN MAUNDS PER ACRE.

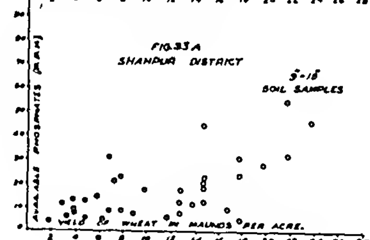


FIG.33 A
SHAHPUR DISTRICT
9"-18"
SOIL SAMPLES
AVAILABLE PHOSPHATES (P.P.M.)
YIELD OF WHEAT IN MAUNDS PER ACRE.

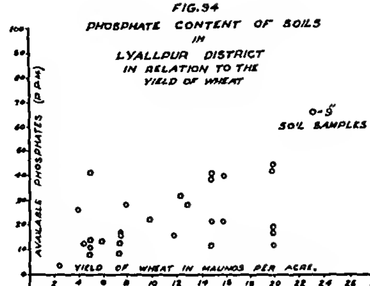


FIG.34
PHOSPHATE CONTENT OF SOILS
IN
LYALLPUR DISTRICT
IN RELATION TO THE
YIELD OF WHEAT
0-9"
SOIL SAMPLES
AVAILABLE PHOSPHATES (P.P.M.)
YIELD OF WHEAT IN MAUNDS PER ACRE.

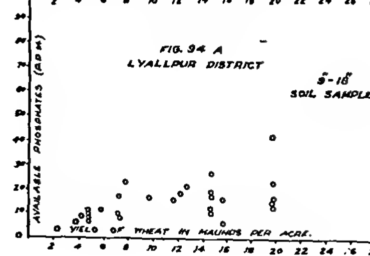


FIG. 34 A
LYALLPUR DISTRICT
9"-18"
SOIL SAMPLES
AVAILABLE PHOSPHATES (P.P.M.)
YIELD OF WHEAT IN MAUNDS PER ACRE.

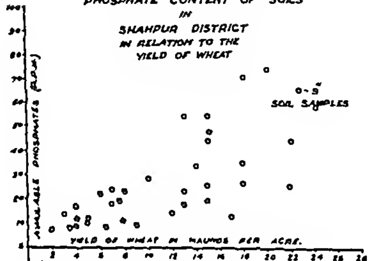


FIG. 93
PHOSPHATE CONTENT OF SOILS
IN
SHAHPUR DISTRICT
IN RELATION TO THE
YIELD OF WHEAT

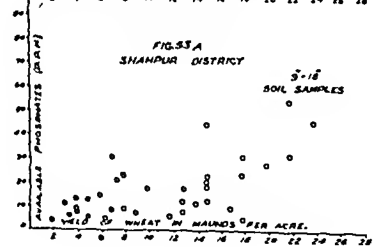


FIG. 93 A
SHAHPUR DISTRICT

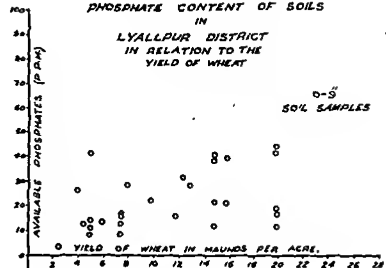


FIG. 94
PHOSPHATE CONTENT OF SOILS
IN
LYALLPUR DISTRICT
IN RELATION TO THE
YIELD OF WHEAT

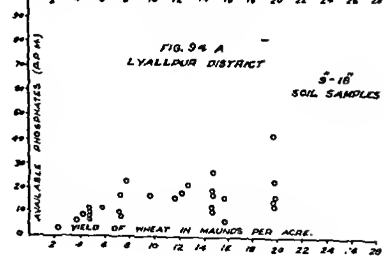
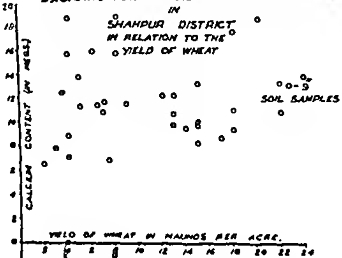


FIG. 94 A
LYALLPUR DISTRICT

FIG.95

EXCHANGEABL CALCIUM CONTENT OF SOILS



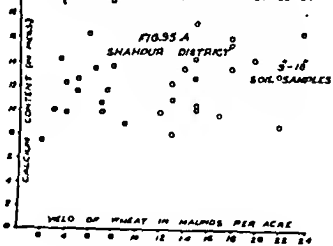
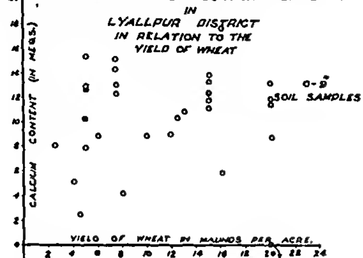
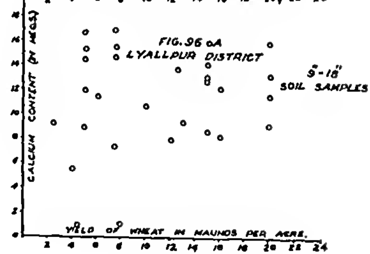


FIG.96

EXCHANGEABLE CALCIUM CONTENT OF SOILS





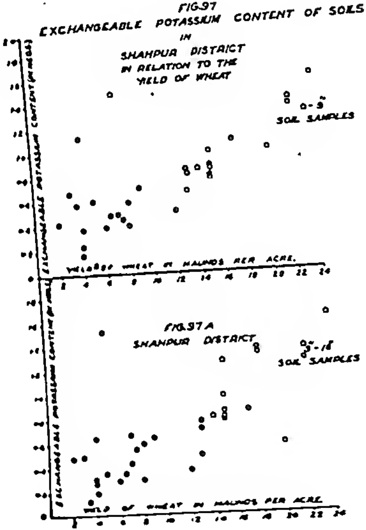


FIG.97
EXCHANGEABLE POTASSIUM CONTENT OF SOILS
IN
SHAHPUR DISTRICT
IN RELATION TO THE
YIELD OF WHEAT
0-9" SOIL SAMPLES
EXCHANGEABLE POTASSIUM CONTENT (IN M.E.Q.)
YIELD OF WHEAT IN MAUNDS PER ACRE.
FIG.97 A
SHAHPUR DISTRICT
9"-18" SOIL SAMPLES
EXCHANGEABLE POTASSIUM CONTENT (IN M.E.Q.)
YIELD OF WHEAT IN MAUNDS PER ACRE.

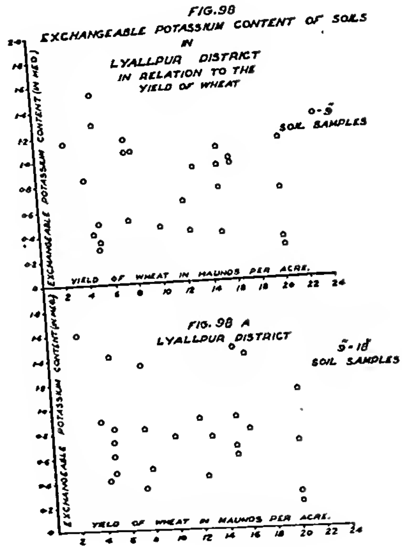


FIG.98
EXCHANGEABLE POTASSIUM CONTENT OF SOILS
IN
LYALLPUR DISTRICT
IN RELATION TO THE
YIELD OF WHEAT
0-9" SOIL SAMPLES
EXCHANGEABLE POTASSIUM CONTENT (IN M.E.Q.)
YIELD OF WHEAT IN MAUNDS PER ACRE.
FIG. 98 A
LYALLPUR DISTRICT
9"-18" SOIL SAMPLES
EXCHANGEABLE POTASSIUM CONTENT (IN M.E.Q.)
YIELD OF WHEAT IN MAUNDS PER ACRE.

FIG. 101
PH OF SOILS
IN
SHAHPUR DISTRICT
IN RELATION TO THE
YIELD OF WHEAT

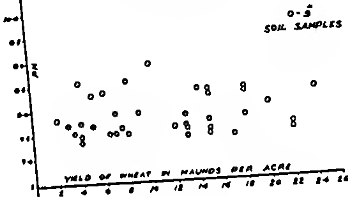


FIG. 101 A
SHAHPUR DISTRICT

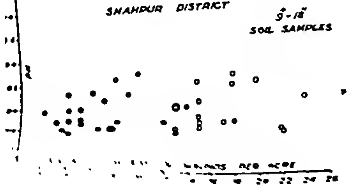


FIG. 102
PH OF SOILS
IN
LYALLPUR DISTRICT
IN RELATION TO THE
YIELD OF WHEAT

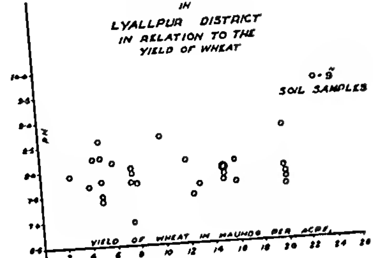


FIG. 102 A
LYALLPUR DISTRICT

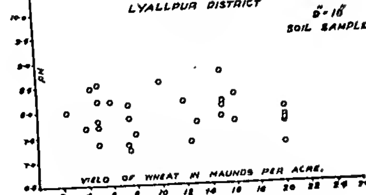


FIG.101
PH OF SOILS
IN
SHAHPUR DISTRICT
IN RELATION TO THE
YIELD OF WHEAT

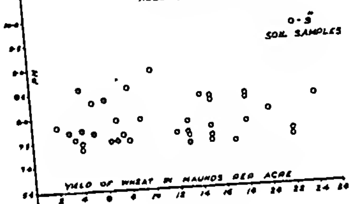


FIG.101 A
SHAHPUR DISTRICT

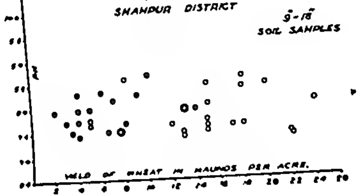


FIG.102
PH OF SOILS
IN
LYALLPUR DISTRICT
IN RELATION TO THE
YIELD OF WHEAT

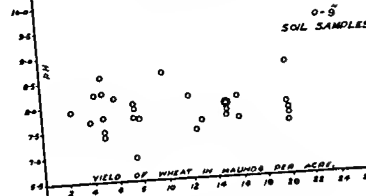
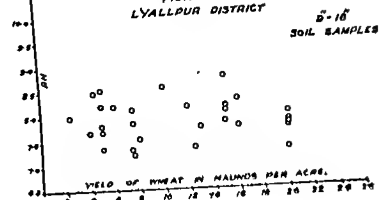


FIG.102 A
LYALLPUR DISTRICT



List of papers published by the Institute Staff in outside journals during the year, 1938-39.

1. Review of Progress of Irrigation in India. By N. K. Bose. (Current Science, January, 1939.)
2. Review of Stream and Channel Flow. By N. K. Bose. (Current Science, March, 1939.)
3. Problems of River Physics and How They are Solved. By N. K. Bose. (The Punjab Engineer, Vol. I, No. 5, pp. 5, 1939.)
4. Mathematics in Irrigation. By N. K. Bose. (Science and Culture, June, 1939.)
5. Extraction of Humus from Soil with Alkalies and its Colorimetric Estimation. By A. N. Puri and Anand Sarup. (Soil Research, 6 : 122, 1938).
6. Isohydric pH Value of Soils and Its Determination. By A. N. Puri and Anand Sarup. (Soil Science, 46 : 49, 1938.)
7. Hydrogen-ion Activity of Colloidal Acids in Soils. By A. N. Puri and A. N. Dua. (Soil Science, 46 : 113, 1938.)
8. Influence of Salts and Soil-Water Ratio on pH Value of Soils. By A. N. Puri and A. G. Asghar. (Soil Science, 46 : 249, 1938).
9. Oxidation-Reduction Potentials in Soils. By A. N. Puri and Anand Sarup. (Soil Science, 46 : 323, 1938.)
10. Interaction between Carbonates and Soils. By A. N. Puri and M. L. Puri. (Soil Science, 46 : 401, 1938).
11. Action of Carbon Dioxide on Soils. By A. N. Puri and H. L. Uppal. (Soil Science, 46 : 467, 1938).
12. Physical Characteristics of Soils : II. Expressing Mechanical Analysis and State of Aggregation of Soils by Single Values. By A. N. Puri and B. R. Puri. (Soil Science, 47 : 77, 1939.)
13. Base Exchange in Soils . I. A. Critical Examination of the Methods of Finding Base Exchange Capacity of Soils. By A. N. Puri and H. L. Uppal. (Soil Science, 47 : 245, 1939.)
14. Physical Characteristics of Soils : III Heat of Wetting. By A. N. Puri and R. C. Hoon. (Soil Science, 47 : 415, 1939.)
15. The Movement of Salts and Moisture in Soil with [illegible] Problem of Thur in the Punjab Canal Colonies. By [illegible] (Punjab Agricultural College Magazine, 6 : 3, [illegible])
16. Efflorescence in Buildings and a New Method of [illegible] Gopal and M. L. Mehta. (Paper No. 222 read in [illegible] Congress, 1939.)
17. [illegible] Water-table. By [illegible] of the Indian Acad[illegible]
18. A Study of the Soils in the Hill Areas of Kashmir [illegible] of Soil Profiles under Deodar, Blue pine Silver [illegible] R. C. Hoon. (Indian Forest Records (New [illegible] 3 : 195, 1938.)

9. Influence of an Upstream Sheet Pile on the Uplift Pressure on a Floor, by N. K. Bose, M.Sc., Ph.D., Harbans Lal Uppal and E. McKenzie Taylor, M.B.E. (Re. 1-4-0 or 1s. 11d.)

10. An Investigation of the Uplift Pressure on a Model of Bay IV, Khanki Weir and the Prototype, by A. N. Khosla, E. McKenzie Taylor, and Harbans Lal Uppal. (Rs. 1-10-0 or 1s.)

11. Pressures under a Model of Panjnad Weir and under the Prototype, by H. L. Uppal. (Re. 0-4-0 or 5d.)

12. Design of Khanki Weir Bay VIII, by J. P. Gunn, and H. L. Uppal. (Re. 0-4-0 or 5d.)

13. Uplift Pressure under a Depressed Floor, by Dr. N. K. Bose, and H. L. Uppal. (Re. 0-7-0 or 8d.)

14. The Effect of an End Sheet Pile on the Pressure Distribution under a Weir Floor and on the Exit Gradient by Dr. N. K. Bose and Harbans Lal Uppal. (Re. 0-14-0 or 1s. 4d.)

15. Punjab Practice in Silt Observations, by Dr. E. McKenzie Taylor, M.B.E., Director, Irrigation Research Institute, Lahore. (India). Re. 0-6-0 or 7d.)

16. The General Theory of the Gradient of Pressure under a structure on permeable foundations with applications to the evaluation of the Gradient at exit for some standard cases, by Jai Krishan Malhotra, and E. McKenzie Taylor. (Re. 0-3-0 or 4d.)

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23. An Investigation of the Inter-Relation of Silt Indices and Discharge Elements for some Regime Channels in the Punjab, by N. K. Bose and J. K. Malhotra. (Re. 1-10 0 or 2s. 5d.).

24. Experiments for Silt Control on a Model of the Emerson Barrage, left undersluices, Left Regulator, with a part of the River Chenab Upstream. By N. K. Bose and Thakar Das Ghulati. (In Press.

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1. An Analysis of the Utilization of Irrigation-Water in Typical Punjab Canals, by B. H. Wilsdon, M.A., B.Sc., I.E.S., Scientific Research Officer, Punjab Irrigation, and Mehta Mukand Lal, B.Sc., L.Ag., Research Assistant, 1930. (Re. 0-8-0 or 9*d*.)

2. The Soils of the Rice Areas of the Gujranwala and Sheikhupura Divisions of the Upper Chenab Canal, by M. L. Mehta. (Re. 0-10-0 or 1*s*.)

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